MEDIUM TACTICAL VEHICLE UNDERBODY ARMOR DEVELOPMENT

A thesis written at

U.S. ARMY TANK AUTOMOTIVE RESEARCH, DEVELOPMENT, AND ENGINEERING CENTER

and submitted to

KETTERING UNIVERSITY

in partial fulfillment
of the requirements for the
degree of

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

by

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June 2010

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **03 MAR 2010**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Medium Tactical Vehicle Underbody Armor Development**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Kyle McLeod**		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000, USA**		8. PERFORMING ORGANIZATION REPORT NUMBER **20600RC2**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) **TACOM/TARDEC** 11. SPONSOR/MONITOR'S REPORT NUMBER(S) **20600RC2**
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**		
13. SUPPLEMENTARY NOTES **Submitted to Kettering University in partial fulfillment of the requirements for the degree of Bachelor OF Science IN Mechanical Engineering, The original document contains color images.**		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**61**	

DISCLAIMER

This thesis is submitted as partial and final fulfillment of the cooperative work experience requirements of Kettering University needed to obtain a Bachelor of Science in Mechanical Engineering Degree.

The conclusions and opinions expressed in this thesis are those of the writer and do not necessarily represent the position of Kettering University or U.S. Army Tank Automotive Research, Development, and Engineering Center, or any of its directors, officers, agents, or employees with respect to the matters discussed.

PREFACE

This thesis represents the capstone of my five years combined academic work at Kettering University and job experience at U.S. Army Tank Automotive Research, Development, and Engineering Center. Academic experiences in mechanical engineering, material science, and computer aided engineering proved to be valuable assets while I developed this thesis and addressed the problem it concerns.

Although this thesis represents the compilation of my own efforts, I would like to acknowledge and extend my sincere gratitude to the following persons for their valuable time and assistance, without whom the completion of this thesis would not have been possible:

1. My family and friends, who know very little about what this thesis entails, yet have influenced it in every way with the values, judgment, and knowledge they have instilled upon me over the years. Their association is truly my most coveted education.

2. The entire TARDEC Blast Mitigation team and ARL Survivability Materials Branch. This thesis is really a reflection of their immense guidance and technical expertise. Bar none, the past two years have been the most challenging, rewarding, and entertaining work environment I have ever experienced.

3. The Tactical Wheeled Vehicle Survivability Army Technical Objective Program, for not only providing the financial backing on which this thesis was conducted, but for granting me the opportunity to support such a pivotal aspect of your program.

4. Dr. Basem Alzahabi. Professor of Mechanical Engineering, for tolerating the vacuity mandated for national security.

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*Not included: Available upon request with valid security clearance

LIST OF ILLUSTRATIONS

*Not included: Available upon request with valid security clearance

Tables

I. INTRODUCTION

Problem Topic

The objective of this thesis is to investigate underbody armor solutions for a Medium Tactical Vehicle (MTV) that mitigate the effects of blast and fragmentation associated with IED events.

Background

The first MTV prototype was designed in 1988. The vehicle's sales have grown the MTV fleet to over 56,000 strong consisting of sixteen variations ("FMTV," 2006). As illustrated by Figure 1, current MTVs are outfitted with the Long Term Armor Strategy (LTAS) cab to enhance occupant protection relative to baseline while enabling the cab configuration to readily change respective of operational requirements via the utilization of Add on Armor (AoA) kits.

Figure 1. MTV outfitted with LTAS crew compartment.

Since the beginning of Operation Iraqi Freedom (Iraq) and Operation Enduring Freedom (Afghanistan) the U.S. Army has encountered a 360 degree battlefield; putting U.S. Army Vehicles at a greater risk of attack from Land Mines, Improvised Explosive Devices (IEDs), and Explosively Formed Penetrators. Support vehicles are particularly vulnerable because they were not originally intended to frequent hostile areas and therefore not substantially armored at their conception.

IEDs are “homemade” explosive devices often consisting unexploded ordnance such as mortars and artillery shells fused to remote detonate. They are directed at foot patrols and military vehicles to inflict injury or death through means of mechanical trauma resulting from blast, fragmentation, and secondary projectiles. IEDs can also be implemented to incapacitate military vehicles, rendering targets extremely vulnerable to enemy ambush. This paper will focus on IEDs directed towards military vehicles, specifically MTVs.

Upon detonation, the burning high explosive generates a massive expansion of hot gases, forming a blast wave. The blast wave produces hazardous soil ejecta and imparts a huge upward compressive force resulting in a potentially deadly transfer of energy to the vehicle and potentially its occupants. Blast can also breach vehicle structures, creating a direct crew compartment entrance for blast flow capable of traumatic amputation. In the case of IEDs, expanding hot gases force the casing to separate, generating high-velocity metallic fragmentations capable of piercing vehicle hulls and causing severe lacerations to occupants.

In 2007, TARDEC was awarded an Army Technical Objective (ATO) to enhance crew and passenger survivability of the current and future Tactical Wheeled Vehicle Fleet through analysis, identification, development and demonstration of an integrated suite of technologies. Accordingly, test "hulls" (simulated lower portion of MTV cabs) were subjected to live fire underbody threats in an effort to demonstrate or determine survivability enhancements achieved by applying underbody "U-kit" armor solutions.

<u>Criteria and Parameter Restrictions</u>

Performance of the U-kit was measured against various criteria. Consequently, the target was inspected/measured as required to obtain the following data:

1. Dynamic deflection of floor panels: acquired via comb gauges
2. Static deflection of floor panels: post event measurements and laser scan data
3. Impulse delivered to target: HS video trajectory measurements
4. Fragment penetration: visual observation

5. Hull weld integrity: visual inspection

6. U-kit serviceability (suitability for repair): general observation

Crew seat and floor pan loading spectrums were also recorded for the purposes of applying analytical tools to determine if blast forces are of sufficient magnitude and duration to incapacitate vehicle crew members. Additionally, all solutions must maintain current MTV performance capacities and occupant ergonomic restrictions.

Methodology

To evaluate U-kit performance, test assets consisting of a salvaged MTV chassis, representative test hulls, and diverse U-kit solutions underwent live-fire testing. U-kit integration studies were used to maintain vehicle performance, occupant ergonomics, and streamline installation. The asset was instrumented and evaluated in concurrence with the criteria established in the above section. In the effort's entirety, numerous data sources were used including: direction observation, physical testing, technical publications, and input from industry renowned experts.

Primary Purpose

The objective of this thesis is to investigate underbody armor solutions for a MTV that mitigate the effects of blast and fragmentation associated with IED events.

Overview

Underbody armor kit functionality was evaluated through experimental testing. The test results were validated against the current requirements for MTV blast mitigation and crew protection. The following chapters detail the steps required for this effort including: test hull design/fabrication, U-kit kit design/fabrication, live fire testing, and data analysis with a correlation to potential threats to occupant injury.

II. TEST ASSET DESIGN AND FABRICATION

Test Hull Design and Fabrication

For the purpose of live fire testing against the intended threat, test hulls were designed to closely replicate the geometric boundary conditions and structural integrity of a MTV's lower half. Utilizing existing CAD data packages in conjunction with physical vehicle reference, all structure above the vehicle's "beltline" was removed. Steel channeling was then added to maintain the cab's strength. I-beams were welded laterally across the hull's top perimeter to allow for the addition of ballasting and mounting of data acquisition devices. Letterkenny Army Depot (LEAD) was contracted to build the test hulls displayed in Figure 2 per the fabrication drawings provided in Appendix A-1.

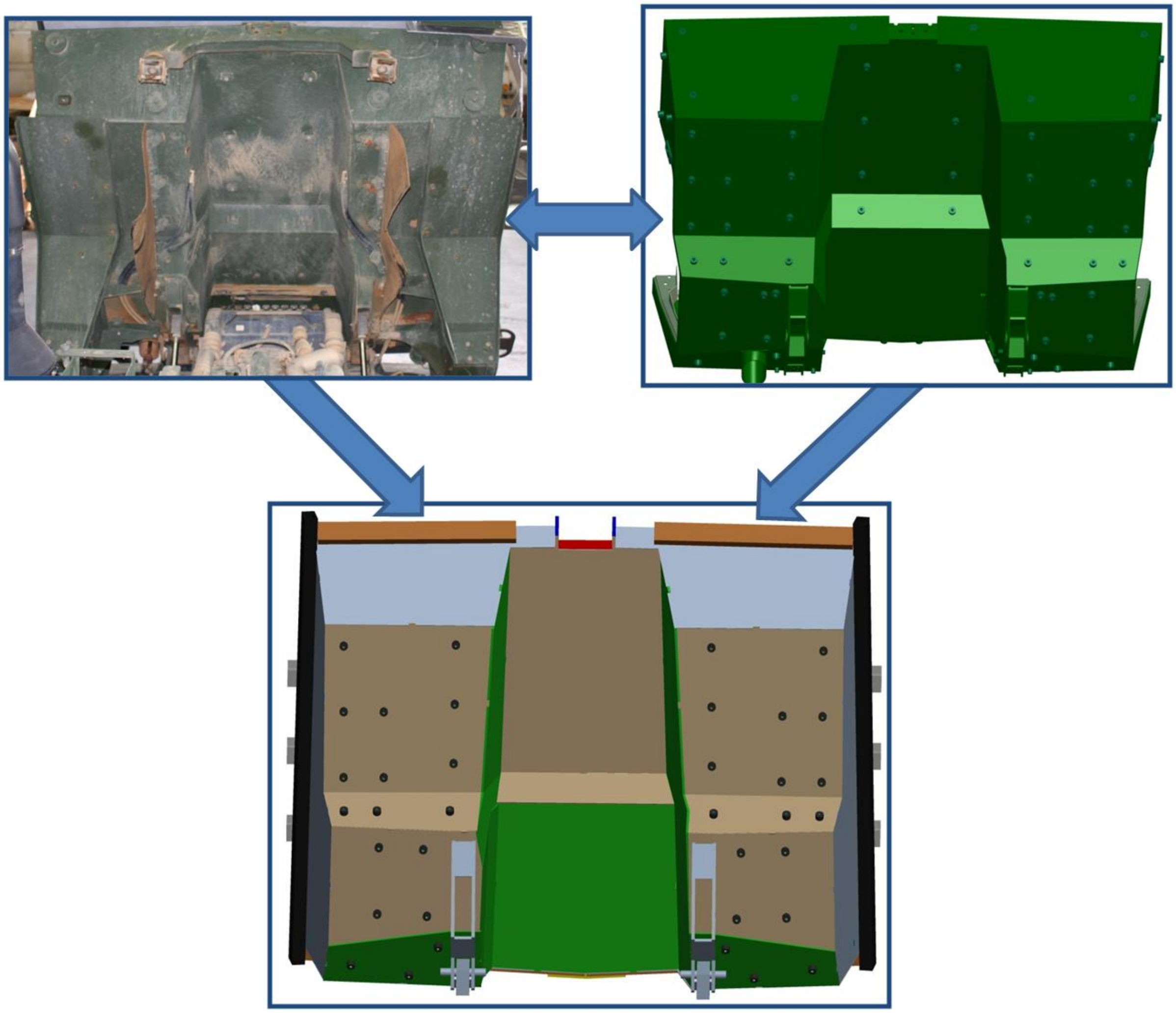

Figure 2. Test hull design progression. *Top Left:* Physical MTV underbody. *Top Right:* CAD data underbody. *Bottom Center:* Designed test hull underbody.

Preliminary Underbody Armor Kit Design

Army Research Laboratory provided multiple armor recipes of differing material types and thicknesses shown in Table 1. These recipes were derived from previous coupon testing against Fragmentation Simulating Projectiles (FSP) accelerated to a velocity representative of the intended threat. R2 was eliminated immediately because of its exorbitant price and limited availability. Several exercises were then completed to most closely integrate said armor recipes onto a MTV. Care was taken to make integration minimally evasive to the vehicle's current design while maintaining vehicle performance and necessary occupant accommodations.

Table 1

<u>Armor Recipe Designations</u>

Armor Recipe Designation	Material	Density (lb / ft^3)	Thickness (inches)	Aerial Density (PSF)
LTAS Baseline (R0)	N/A	0	0	0
R1	[redacted]	[redacted]	1.125	[redacted]
~~R2~~	[redacted]	[redacted]	~~1.65~~	[redacted]
R3	[redacted]	[redacted]	2	[redacted]

<u>Note.</u> Remaining data available upon request and valid security clearance.

First, a space claim assessment was conducted to identify immediate mechanical interferences. Visual examination revealed a critical constraint of 1.25 inches between the cab underbody and the vehicle's sidesteps as illustrated by Figure 3. Modifying the side step integration was pursued to accommodate R3 space claim requirements, but was determined unfeasible due to numerous implications regarding existing vehicle subsystems such as brake components, steering linkages, etc. To investigate drivetrain interaction, polystyrene foam extruded to 1.5 inches thick was applied to the respective drivetrain tunnel. It was determined that a thickness of 1.5 inches was physically available on the horizontal tunnel plates; the vertical tunnel plates interacted too closely with the MTV drivetrain.

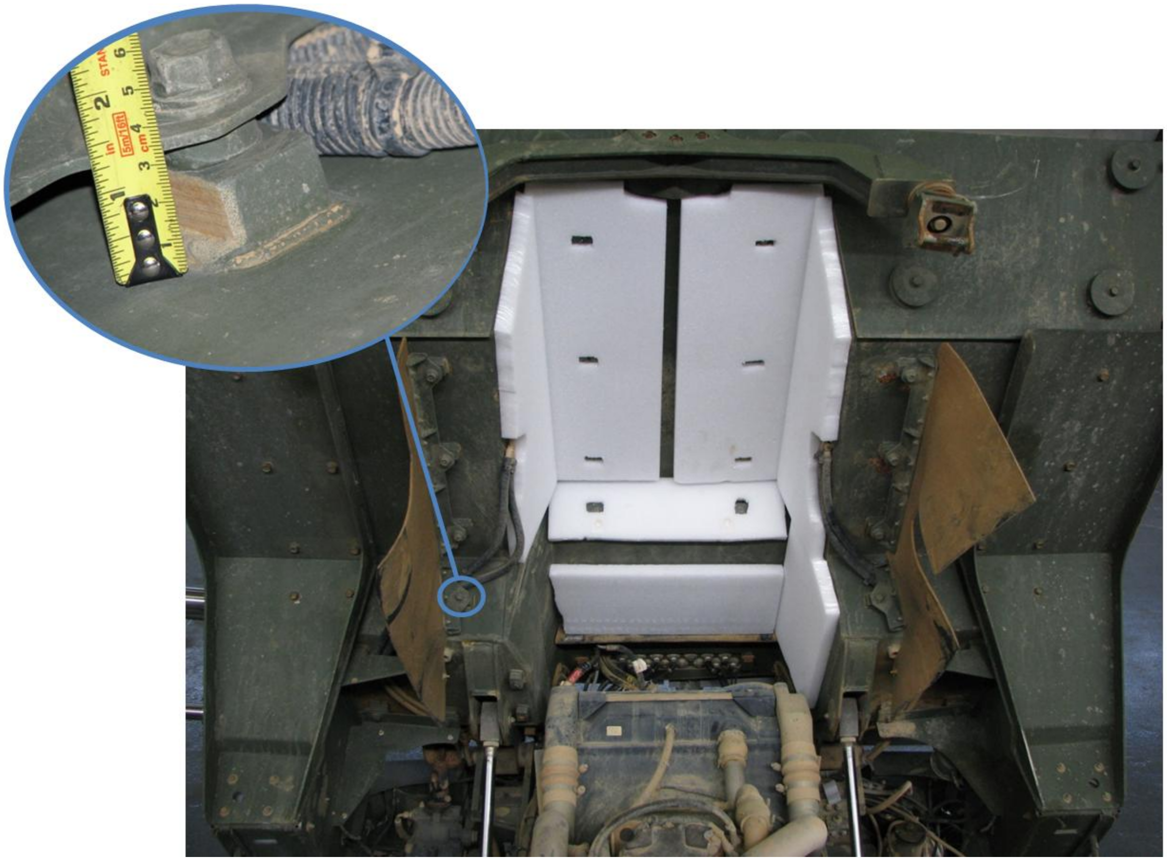

Figure 3. Drivetrain tunnel space claim assessment using extruded polystyrene. *Top Left*: Maximum clearance to sidestep.

Using knowledge gained from the space claim assessment, a rudimentary U-kit was designed representing the best case scenario of armor coverage and thickness physically allowed on a MTV underbody without rigorous retrofitting, shown in Figure 4. All U-kit plates were constrained to 1.25 inches to preserve the current sidestep design and ensure no mechanical interferences with the drivetrain. This allowed R1 to be readily integrated. However, R3 exceeded the space claim, requiring reevaluation to maintain its ballistic requirements against the objective threat.

Working with TARDEC's Concept Analysis System Simulation & Integration (CASSI) team, space claims were explored inside the cab. Using a 95 percentile male, it was determined 1 inch of clearance was available. ARL was approached with this allowance in addition to the 1.25 inch underbody constraint and provided a hybrid solution consisting of an external armor and 0.99 inch interior spall liner. This solution was proved out through additional iterations of FSP coupon testing.

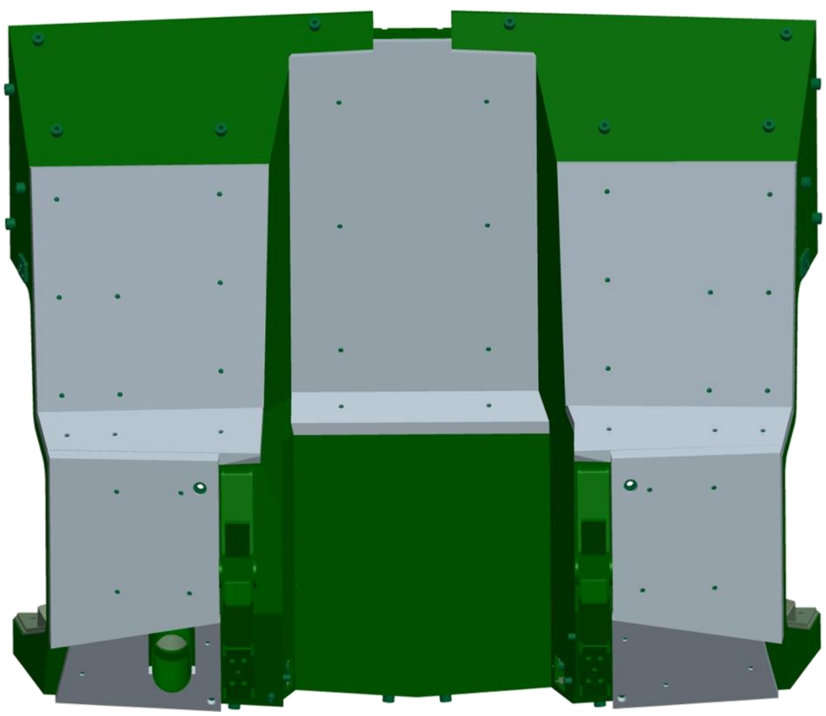

Figure 4. Prototype U-kit design.

Vehicle Performance Considerations

To better understand the performance implications of up-armoring the drivetrain tunnel, a prototype U-kit was fabricated. TARDEC's Ground Vehicle Power and

Mobility Team (GVPM) performed a Full Load Cooling Test (FLCT) on a MTV to evaluate the vehicle cooling performance at various Tractive Effort (TE) to weight ratios. Testing was conducted within a 100 ºF ambient environment test cell, heated by solar loading. Multiple iterations were run with and without the exterior drivetrain tunnel armor installed. The test results are provided in Table 2, below.

Table 2

<u>Summary of FLCT Critical Temperature Data at 100ºF Ambient</u>

Vehicle Configuration:	Limit	Test point			
Without Exterior Tunnel		**0.35 TE**	**0.40 TE**	**0.45 TE**	**0.50 TE**
Air in test cell, ambient(ºF)	NA	100	100	100	100
Coolant into radiator (ºF)	230	227.36	227.01	227.33	229.46
Oil-engine sump (ºF)	275	268.18	264.43	263.56	264.36
Oil-transmission sump (ºF)	260	242.04	242.3	243.28	246.97
Dropbox sump (ºF)	300	254.24	253.72	253.92	256.98
Oil before trans aux cooler (ºF)	300	259.69	263.35	265.01	273.18
Dyno Torque (ft lbs)	NA	3541.96	4090.05	4590.53	5080.73
Engine Speed (RPM)	NA	2385.71	2156.14	2083.37	2020.13
Vehicle Configuration:	Limit	Test point			
With Exterior Tunnel Armor		**0.35 TE**	**0.40 TE**	**0.45 TE**	**0.50 TE***
Air in test cell, ambient(ºF)	NA	100	100	100	100
Coolant into radiator (ºF)	230	229.37	228.73	229.04	230.71
Oil-engine sump (ºF)	275	269.97	265.7	264.86	265.29
Oil-transmission sump (ºF)	260	244.64	244.77	245.33	248.26
Dropbox sump (ºF)	300	256.86	256.51	256.80	258.39
Oil before trans aux cooler (ºF)	300	258.95	264.39	266.55	273.86
Dyno Torque (ft lbs)	NA	3544.65	4064.17	4582.1	5078.52
Engine Speed (RPM)	NA	2376.54	2156.38	2083.79	2019.28
*Temperature limit exceeded and test point concluded before temperatures stabilized					

<u>Note.</u> Red numbers indicate temperature exceeded limit.

With the inclusion of exterior tunnel armor, the MTV coolant cycling back into the radiator exceeded acceptable temperature ranges. To preserve the vehicle's mechanical integrity, testing was halted before temperatures were allowed to stabilize at 0.50 TE. It was concluded that exterior drivetrain tunnel armor violated the MTV's cooling requirements, thereby jeopardizing operational capabilities, and requiring consideration of alternative AoA avenues.

Similar to the steps utilized with the integration of R3, CASSI was again utilized to verify tolerable space claims inside the MTV crew compartment. TARDEC worked jointly with ARL to establish an interior drivetrain tunnel solution that balanced ballistic integrity with integration requirements. The final solution was optimized by exploiting the LTAS cab's complex obliquity patterns, allowing for less material on the tunnel sides. The tunnel's configuration also posed as a vicinity for potential blast traps. Accordingly, angled A36 steel channel was used to reinforce susceptible weld seams, guarding against excessive forces directed towards the tunnel region and avoiding any weld seam breach issues.

The proposed solution was modeled first in computer aided engineering software and then fabricated on site at ATC for subjection to live-fire testing and subsequent evaluation. Figure 5 below, portrays the drivetrain tunnel's interior before AoA and Figure 6 depicts the resulting interior tunnel liner modifications. Areas of light gray represent armor and the darker gray pieces illustrate the weld reinforcements.

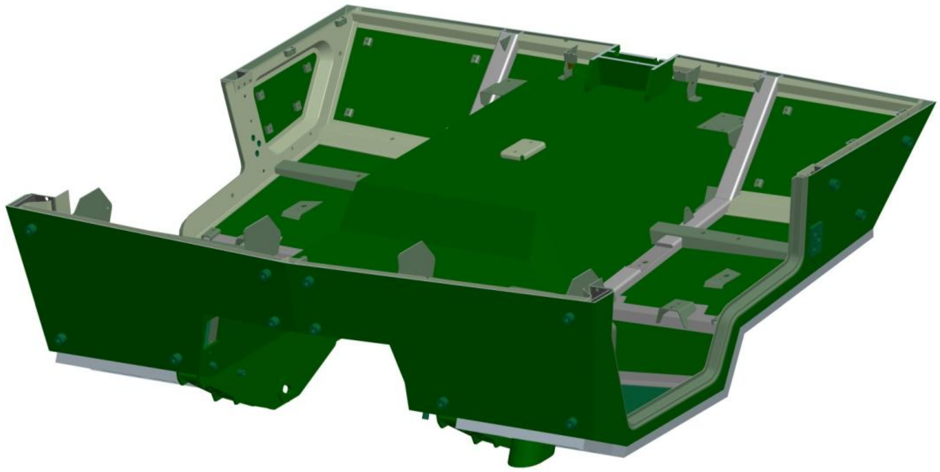

Figure 5. Baseline drivetrain tunnel.

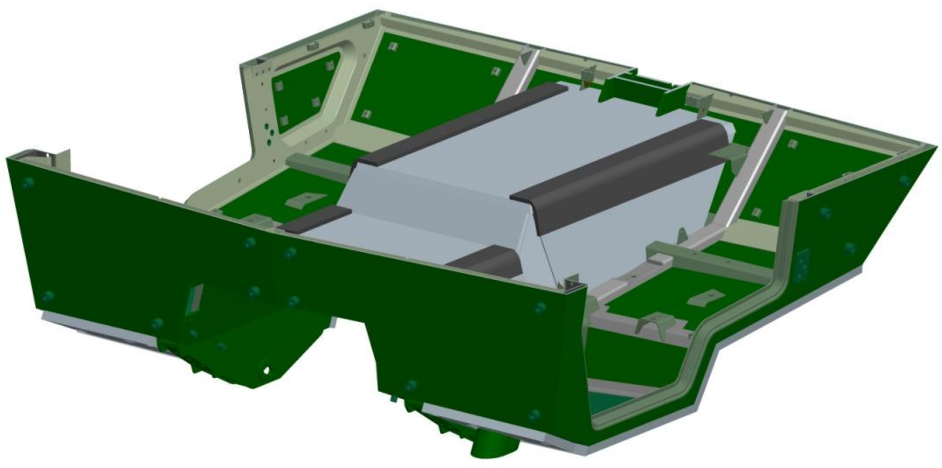

Figure 6. Drivetrain tunnel with interior liner modifications.

III. LIVE FIRE TESTING

Test Setup

MTVs exhibit a cab-over-engine configuration; making the manner in which an IED interacts with the vehicle very complex. Blast waves and fragmentation must first past through or around numerous obstacles before actually arriving at the crew compartment. Said interferences can be either aid or hinder armor performance. For this reason, a decommissioned chassis was used for mounting the test hulls. Opting for an entire chassis instead of a more elementary test fixture allowed for the inclusion of suspension and drivetrain components that directly affect gross vehicle response, blast flow, and fragmentation resistance of an actual MTV. The vehicle's existing cab was removed and attachment points were modified to accept the test hulls as shown in figure 7 (original photograph available upon request with valid security clearance). Severely damaged components were removed altogether to maintain a degree of repeatability amongst tests. Wood cribbing was used to level the vehicle, creating a standoff distance from the ground to the crew compartment equal to that of an actual MTV. Features deemed critical to U-kit performance were maintained and repair as needed between tests. To create a representative front axle weight, approximately 11,000 lbs of ballasting was applied on top of the laterally placed I-beams, accounting for the weight of missing masses and ensuring an accurate vehicle preload.

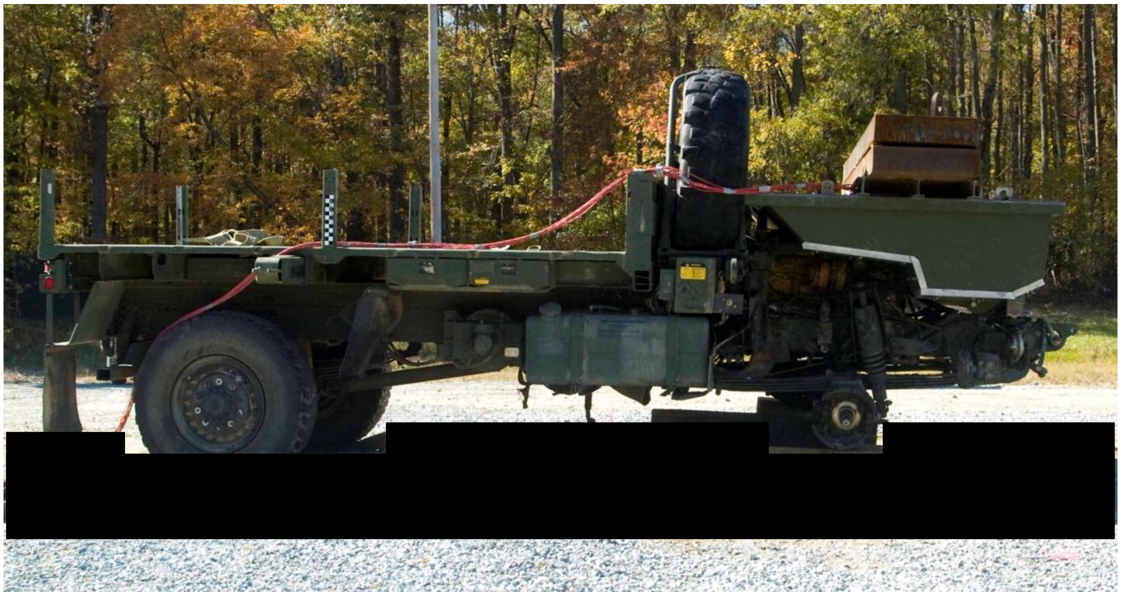

Figure 7. Live Fire Test Setup

Instrumentation and Inspection

To evaluate the U-kit functionality against IED's effects, a variety of data acquisition methods were required. A total of six tri-axial accelerometer "packs" were installed for each test. Instrumentation rings were first tack welded on each of the driver, TC, and gunner ballasts and their respective floor pan locations. One piezoresistive strain gage accelerometer was then attached via a Low Frequency Foam Isolated (LOFFI) mount to record the vertical axis. The locations of said packs are pictorially represented by the blue circles in Figure 8.

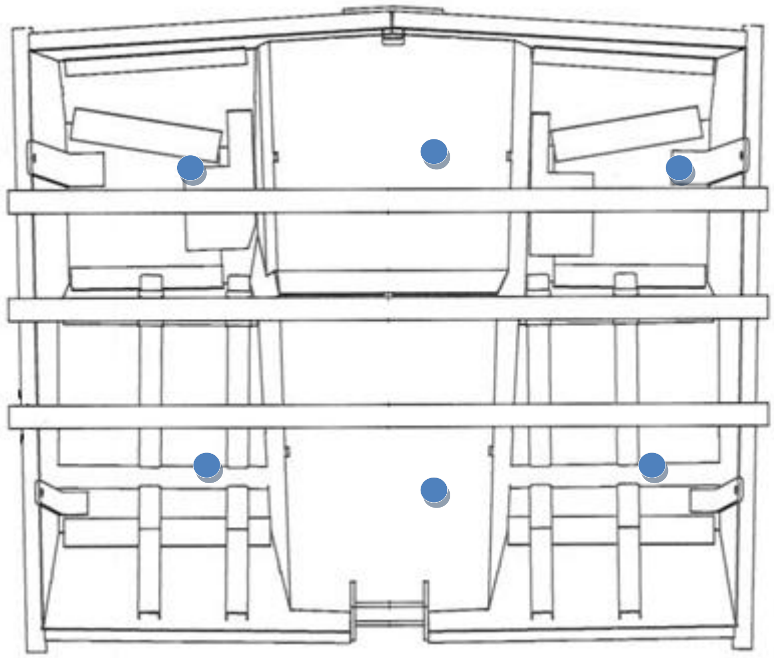

Figure 8: Representation of tri-axial accelerometer pack locations (illustrated by blue circles).

LOFFI mounts are a type of mechanical isolator developed specifically to shield accelerometers from the high frequency shocks associated with live fire testing. They are required for the vertical axis because high frequencies can generate resonance, and if left undamped can destroy the instrumentation (Batemanm Brown & Nusser, 2000). To complete a “pack”, two piezoresistive strain gage accelerators were mounted next to the LOFFI mount in a biaxial array, recording lateral and longitudinal data, as shown in Figure 8. For precision, all eighteen channels were synchronized to a single clock triggered by the initiation of the event. All channels remained active until target touchdown occurred and macroscopic settling ceased. The captured data was subsequently filtered and analyzed to verify consistency amongst events and determine crew survivability.

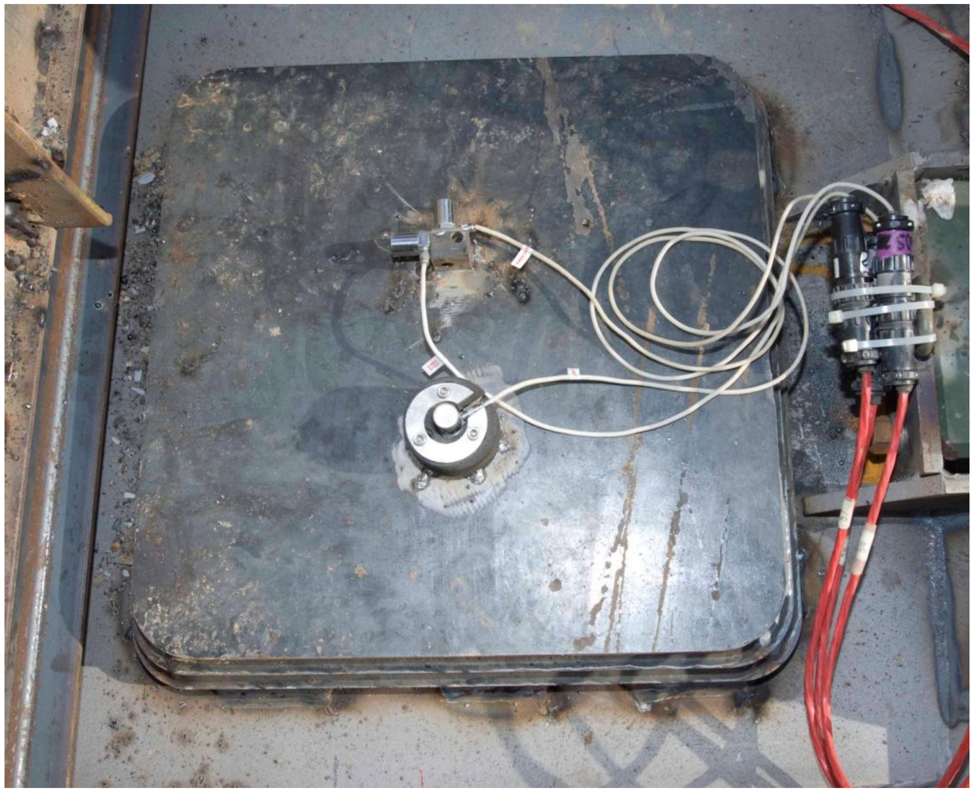

Figure 9. Installed tri-axial accelerometer “pack”.

To judge floor deformation, laser scanning was used in conjunction with comb gauges. Pre and post event floor surface laser scans were taken. Pre-event scans were then compared to post even scans to determine static floor deflection. For dynamic deflection, comb gauges were positioned 0.5inches above the driver, TC, and gunner floor pan locations and welded to the laterally mounted I-beams, as illustrated by Figure 9. The comb gauge’s thin sheet metal construction allows the “teeth” to bend incrementally, capturing maximum floor deformation.

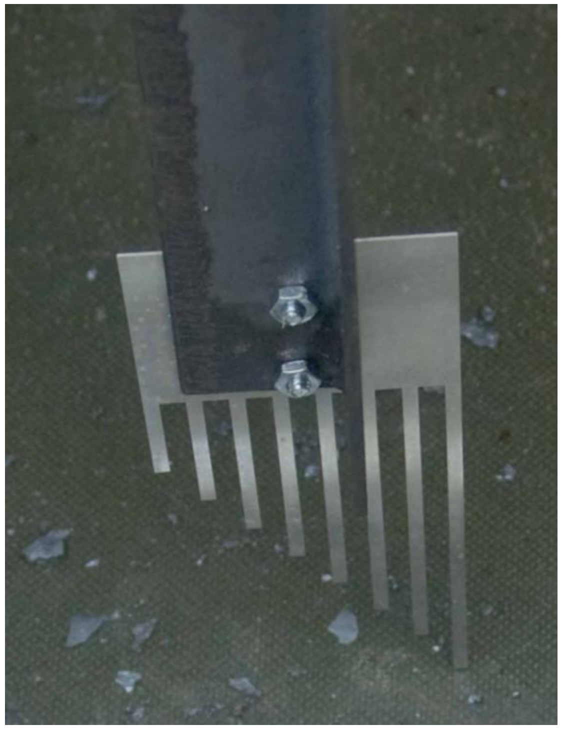

Figure 10. Comb gauge example.

High Speed (HS) cameras and fiduciary markers were incorporated to track system trajectory and facilitate a qualitative understanding of the threat/hull interaction. HS cameras provide a precise mechanism for timing vertical motion while fiduciary markers offer scaled measurement points. Combining these data points allows one to extrapolate the gross impulse applied to the system (Gallagher, P.J. 2008). Accordingly, HS Cameras were positioned such that two hull surfaces were viewed simultaneously and fiduciary markers were positioned generously on the test asset to establish scaling as portrayed in Figure 11.

Figure 11. Fiduciary marker application.

For post event assessments and historical record keeping, still photography was conducted both pre and post event. Particular attention was paid to capturing detailed photographic evidence of comb gauge positions; test hull orientation relative to the ground; instrumented crew ballasting and floor panels; and any resulting craters. To supplement the aforementioned photography and ensure test consistency; autographical data points were recorded pre and post event. Key areas of interest included: measured crater size, pre and post event vehicular standoffs, and general observations regarding weld integrity, breaches, penetrations, and deflections.

The measures detailed above made certain that a wealth of useable knowledge was gained post event, enhancing one's ability to conduct a thorough and accurate analysis of all pertinent factors. Redundant data acquisition methodologies helped mitigate negated data risks.

Test 1

To establish the vehicle's baseline, Test 1 (T1) incorporated a test hull without any AoA. Accompanying post-shot evaluation is available in Appendix B-1 upon request with valid security clearance.

Test 2

Test 2 (T2) incorporated a R1 U-kit and interior drivetrain tunnel reinforcement. Accompanying post-shot evaluation is available in Appendix B-2 upon request with valid security clearance.

Test 3

Test 3 (T3) incorporated a modified R3 U-kit with interior spall lining and drivetrain tunnel reinforcement. Accompanying post-shot evaluation is available in Appendix B-3 upon request with valid security clearance.

Accelerometer Data Analysis

Thorough analysis of the acceleration data captured from T1, T2, and T3 was conducted to quantify occupant accelerations and evaluate feasible means of mitigating potential occupant injury derived from blast forces. Also, accelerometer data was compared among all three tests to ensure that the applied threat behaved in a relatively consistent manner. The solution exhibited in T3 proved most effective, reducing occupant ballast impulse values by a magnitude roughly twice that of those experienced in T1 or T2. A complete dissertation of the data analysis conducted including accompanying plots, trends, and correlations are available in Appendix C-1 upon request with valid security clearance.

IV. CONCLUSIONS AND RECOMMENDATIONS

Underbody armor kits represent only one aspect of a plethora of occupant protection technologies ranging from crushable floors to mine blast seating and energy absorbing interior appliqués. Said technologies are most advantageous when integrated as a system, rather than stand alone entities. Consequently, when selecting a given solution, one must consider not only the kit's individual performance, but how the kit will impact accompanying occupant protection technologies.

In addition to the aforementioned hull testing effort, Modeling and Simulation (M&S) was performed by CASSI Analytics using finite element method software. Applying multiple U-kit solutions to a MTV cab model, iterations of differing threat scenarios were explored to predict potential outcomes against under vehicle blast and fragmenting threats. The accelerometer data captured from live fire testing was also incorporated to continue development and validation of the advanced numerical models used, allowing for more robust models in future endeavors. M&S offers a quick turn-around and cost-effective means of investigating ground vehicle survivability. It is an excellent mechanism to support, but not replace, live fire testing and could be pursed at the system level to further enhance MTV survivability.

Conclusions

Based on the results of live fire testing and subsequent data analysis, the following conclusions were ascertained.

1. Both T2 and T3 solutions are capable of defeating objective threat.

2. T2 represents a relatively more cost-effective solution, exhibiting a homogenous recipe; albeit at a substantial weight impact.

3. T3 offers a more complex, expensive solution that minimizes weight and exhibits the greatest impulse mitigation; however its required internal space claim eliminates the potential for future crush floor applications.

Recommendations

Hull testing is a viable means of investigating a given U-kit's ability to mitigate blast and fragmentation effects associated with IED events, but in no way offers the fidelity associated with full vehicle testing. Accordingly, it is recommended that full vehicle live fire testing be conducted to:

1. Ensure additional occupant protection technologies work cohesively to achieve optimal crew survivability.

2. Validate if crew compartment blast overpressures are survivable and to eradicate blast vulnerabilities as required.

3. Identify structural vulnerabilities that may be present within the vehicle structure at the system level, such as door latches, interior component mounts, etc.

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ACRONYM LIST

AoA	Add on Armor
ARL	Army Research Laboratory
ATC	Aberdeen Test Center
ATO	Army Technical Objective
CASSI	Concept Analysis System Simulation & Integration
EFP	Explosively Form Penetrator
FLCT	Full Load Cooling Test
FSP	Fragment Simulating Projectile
GVPM	Ground Vehicle Power and Mobility
HS	High Speed
IED	Improvised Explosive Device
LEAD	Letterkenny Army Depot
LOFFI	Low Frequency Foam Isolated
LTAS	Long Term Armor Strategy
M&S	Modeling and Simulation
MTV	Medium Tactical Vehicle
TACOM	Tank-Automotive Command
TARDEC	Tank-Automotive Research Development and Engineering Center
TC	Tank-Commander
TE	Tractive Effort

APPENDICES

APPENDIX A

TEST HULL DETAILED DESIGN DRAWINGS

1. REMOVE BURRS AND BREAK SHARP EDGES
2. FINISH PER 5.1.1 AND 20.34 (COLOR# 34094) AND 24.17 (COLOR# 17925) OF MIL-STD-171

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
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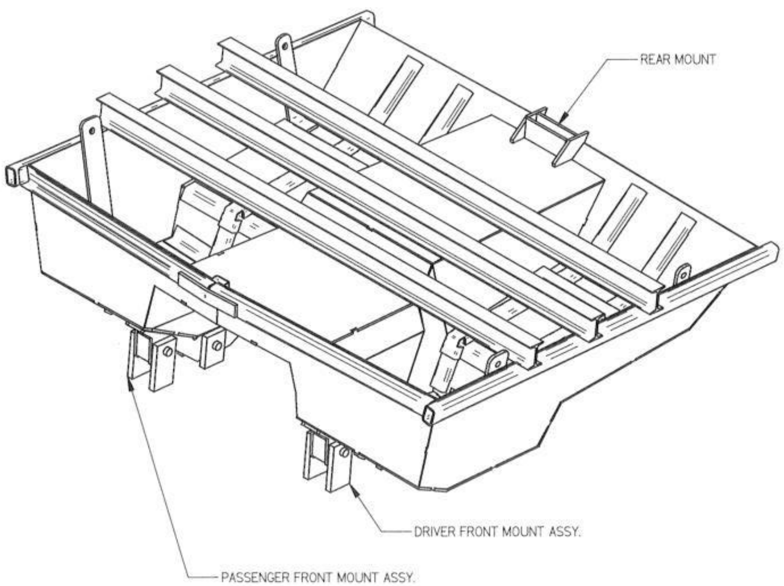
B	SEE DCN FMTV_TUB-0000B	10/20/06	JF



Find No.	Qty.	Part Number	Description
66*	1		Passenger Front Mount Rear Base, .50" A36 Steel
65	1	Rectangular tube 3 x 2 x 1/4	Driver Rear Brace, 2" x 3" A36 Tube(0 .25W)
64	2	Rectangular tube 3 x 2 x 0.25	Side Bracing Tube
63	3	S 4 x 9.5	92" Equipment Support I-Beam, A36 S4 x 9.5 I-Beam
62	1	Rectangular tube 3 x 2 x 1/4	Passenger Front Brace, 2" x 3" A36 Tube(0 .25W)
61	1	Rectangular tube 3 x 2 x 1/4	Driver Front Brace, 2" x 3" A36 Tube(0 .25W)
60	1	Rectangular tube 3 x 2 x 1/4	Passenger Rear Brace, 2" x 3" A36 Tube(0 .25W)
59	1		Passenger Front Lifting Eyelet, .50" A36 Steel
58	2		Rear Lifting Eyelet, .50" A36 Steel
57	1		Driver Front Lifting Eyelet, .50" A36 Steel
56	1		Front Brace Joining Plate, .50" A36 Steel
55	36		1.25 O.D., 1/2"-13 Tapped Boss, 1.25 Dia. 4140 Rnd. Stk.
54*	1		Driver Front Mount Side Plate, .50" A36 Steel
53*	1		Driver Front Mount Inner Side Plate, .50" A36 Steel
52*	1		Driver Front Mount Front Base, .50" A36 Steel
51*	2		Driver Front Mount Triangle Support, .50" A36 Steel
50*	1		Driver Front Mount Rear Base, .50" A36 Steel
49*	4		Rear Fixture Block, 1" A36 Steel
48*	4		Front Fixture Block, 1" A36 Steel
47*	4		Hinge Bar, 1.25" A36 Rnd. Stock
45*	2		Passenger Front Mount Triangle Support, .50" A36 Steel
44*	1		Passenger Front Mount Front Base, .50" A36 Steel
43*	2		Passenger Front Mount Side Plate, .50" A36 Steel
42*	2		Rear Mount Side Support, .50" A36 Steel
41*	2		Rear Mount Center Support, .50" A36 Steel
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39	1		
38	1		
37	1		
36	1		

Find No.	Qty.	Part Number	Description
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22	1		
21	1		
20	1		
19	2		
18	2		
17	1		
16	4		Channel Joint Reinforcement, .125" A36 Steel
15	4		Front Plate Vert. Reinforcement, .125" A36 Steel
14	1		Driver Floor Mounting Brkt. Reinforcement, .25" A36 Steel
13	1		Passenger Floor Mounting Brkt. Reinforcement, .25" A36 Steel
11	1		Driver Cross Reinforcement, .125" A36 Steel
10	1		Passenger Cross Reinforcement, .125" A36 Steel
9	4		Seat Pan Vert. Reinforcement, .125" A36 Steel
8	4		Seat Pan Reinforcement, .125" A36 Steel
7	1		Driver Knee Guard Plate, .125" A36 Steel
6	1		Driver Front Angled Plate, .125" A36 Steel
5	1		Passenger Front Angled Plate, .125" A36 Steel
4	2		Front Seam Plate, .125" A36 Steel
3	2		Passenger Lower Vert. Guard, .125" A36 Steel
2	1		Passenger Knee Guard Plate, .125" A36 Steel
1	2		Rear Angled Plate, .125" A36 Steel

FIND NO.	QTY REQD	PART NO. OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	NOTE

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON FRACTIONS DECIMALS ANGLES
XX ±.04 ±1°
XXX ±.010

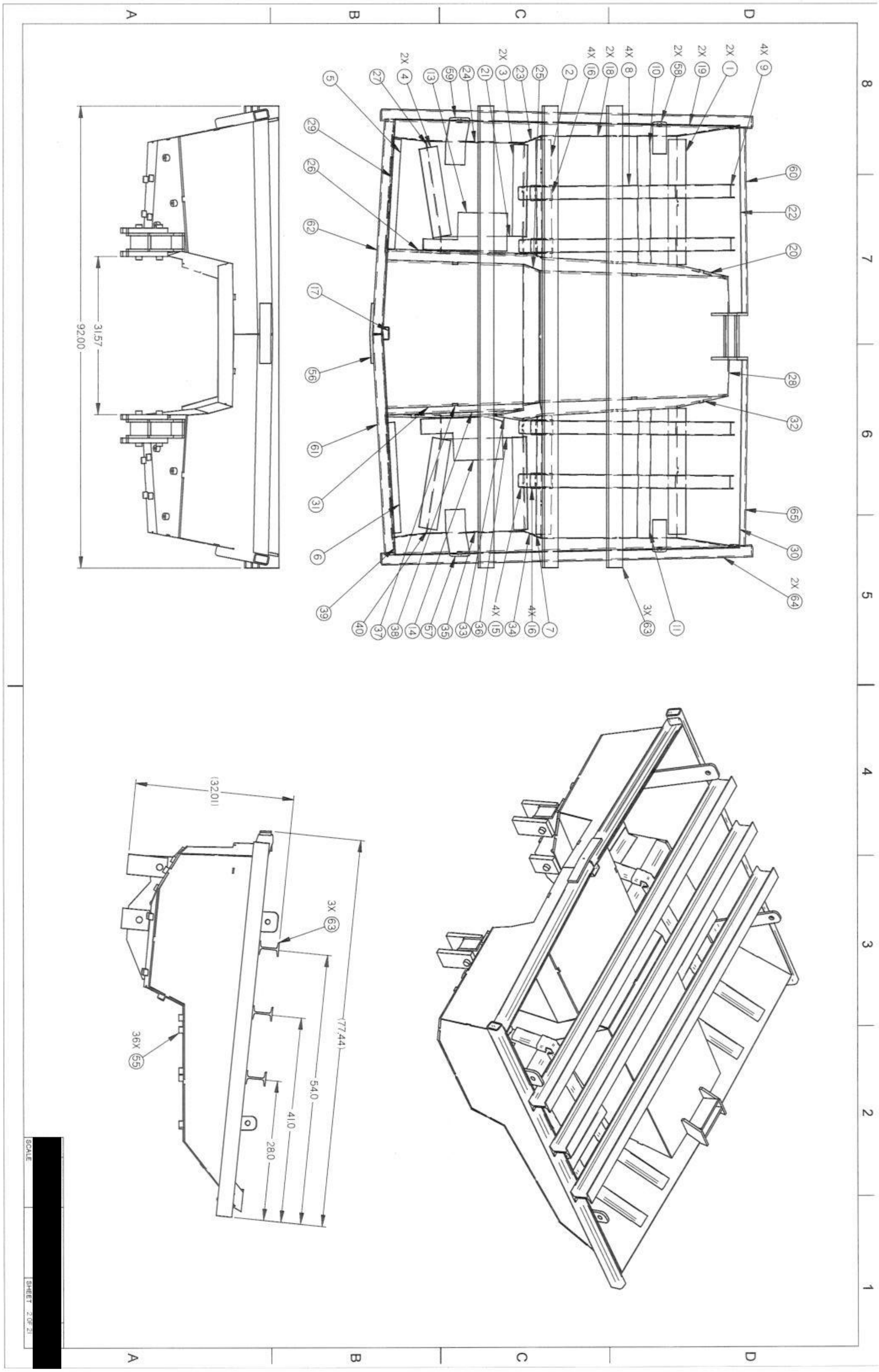
MATERIAL

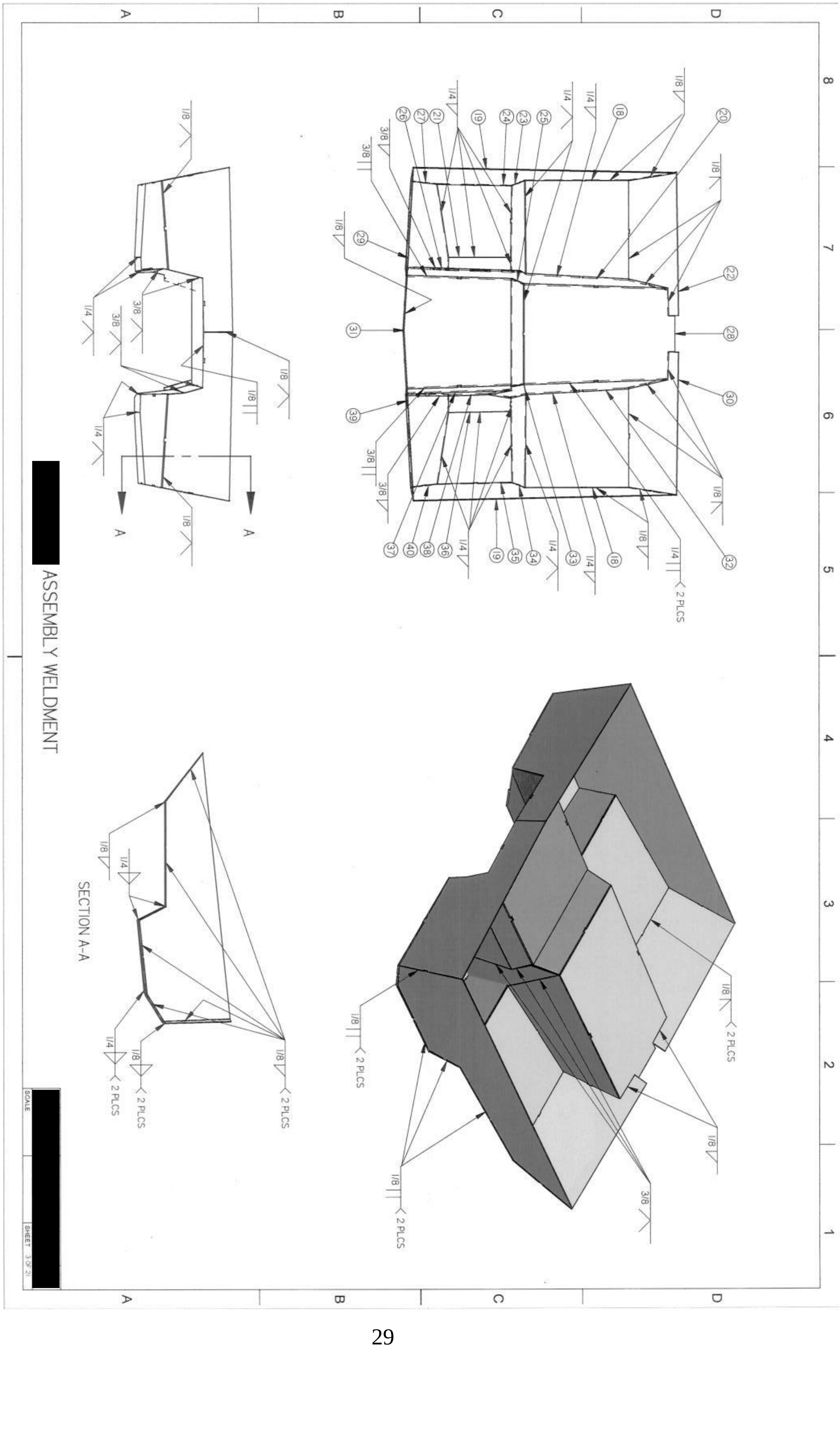
DRAWN J. FRIDAY
CHECKED
REVIEWED
APPROVED
DATE 07 May 2007

[redacted]

SIZE D | CAGE CODE 0NDM7 | [redacted] | REV B
SCALE | SHEET [redacted] OF 21

REVISION | SHEET — SHEET REVISION RECORD
NEXT ASSY | USED ON — APPLICATION

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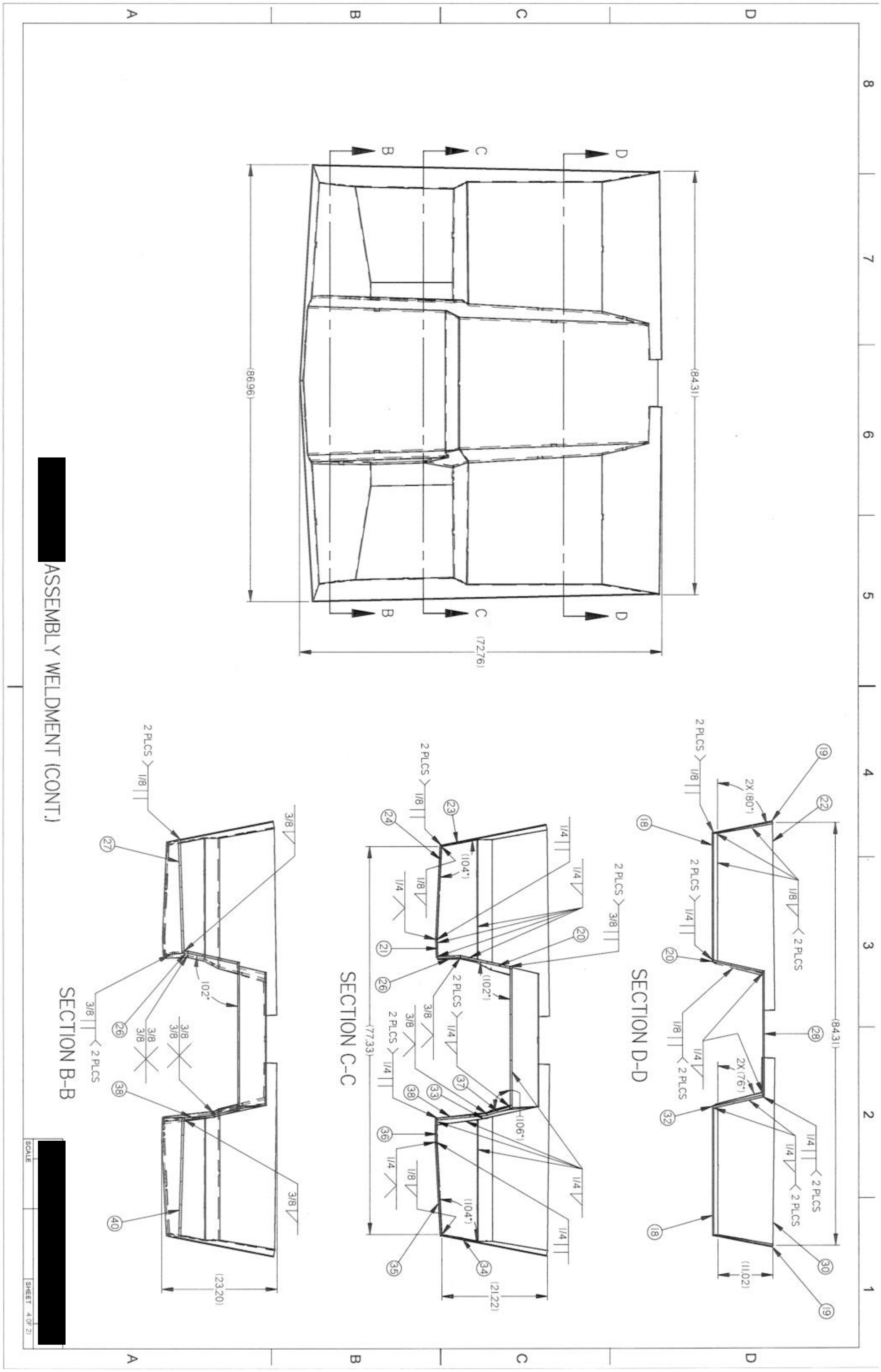
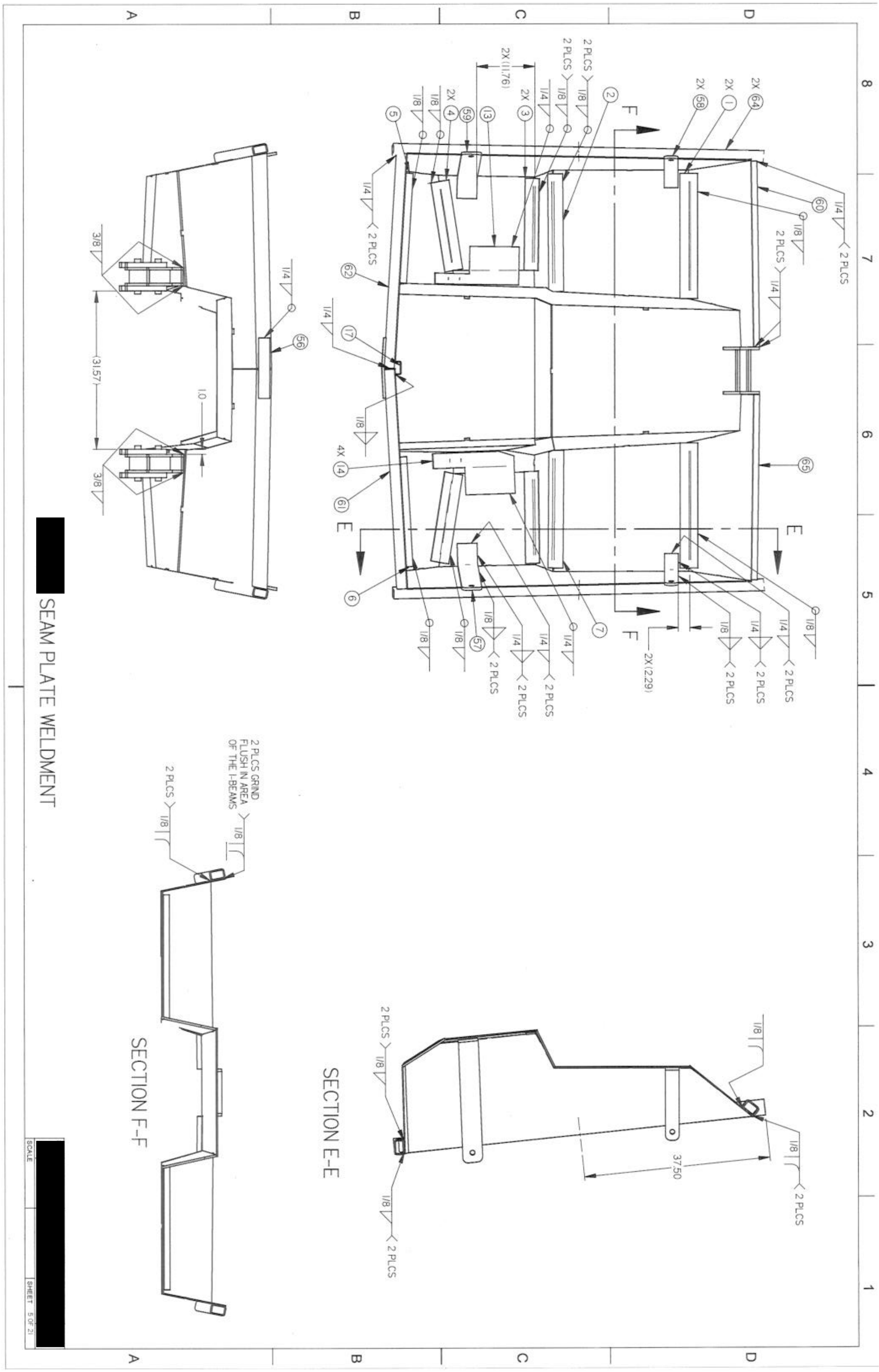
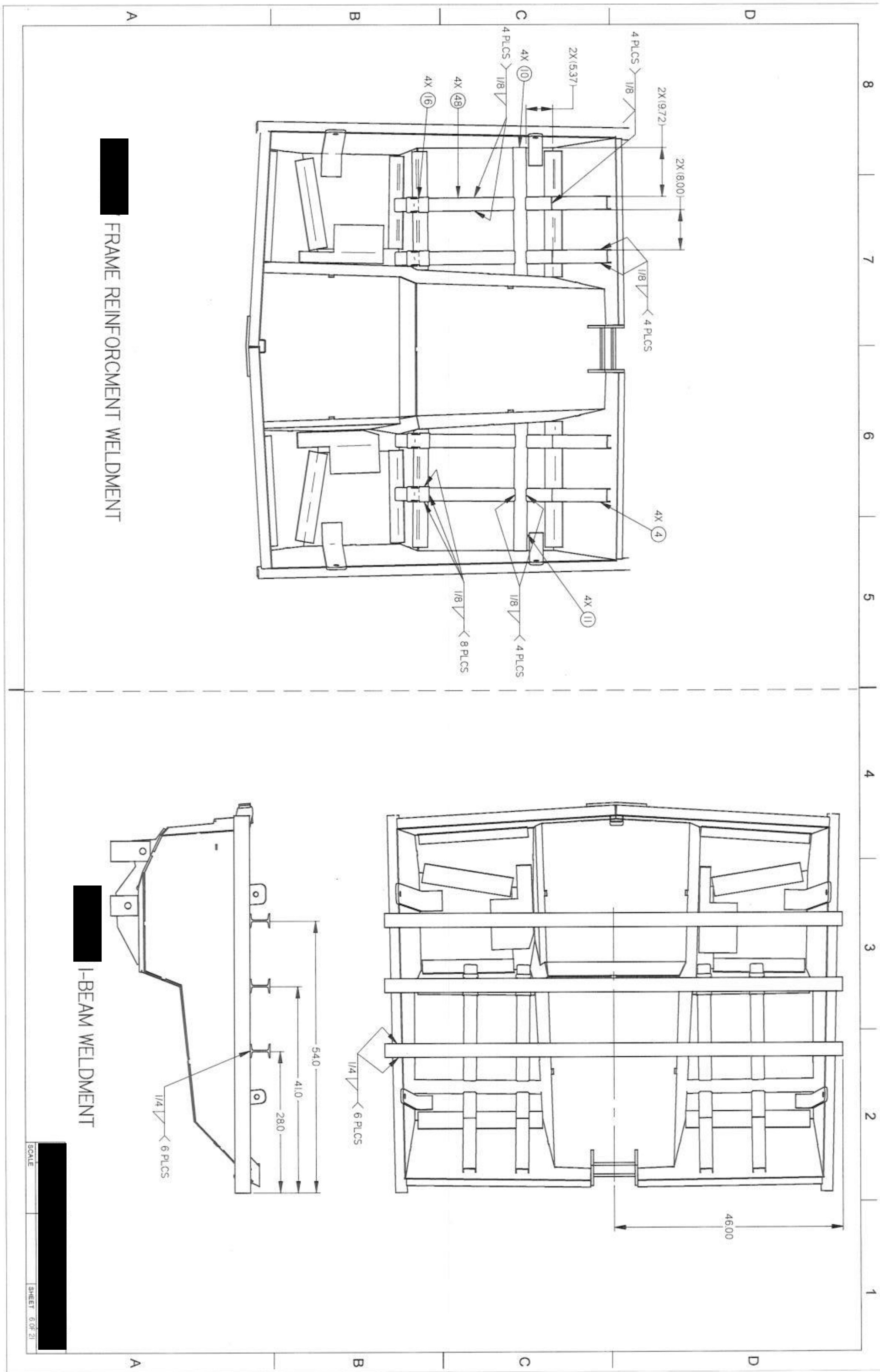
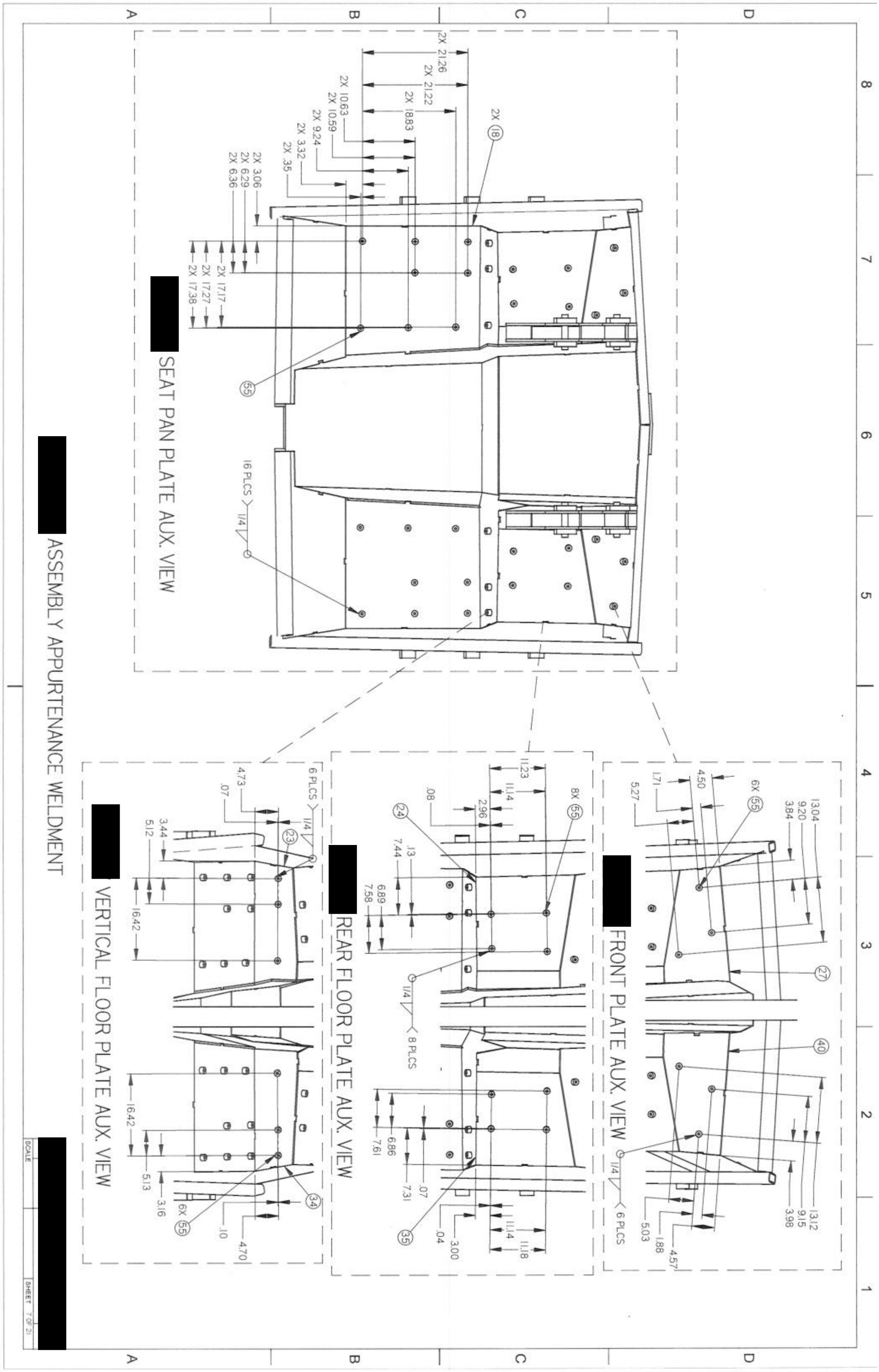
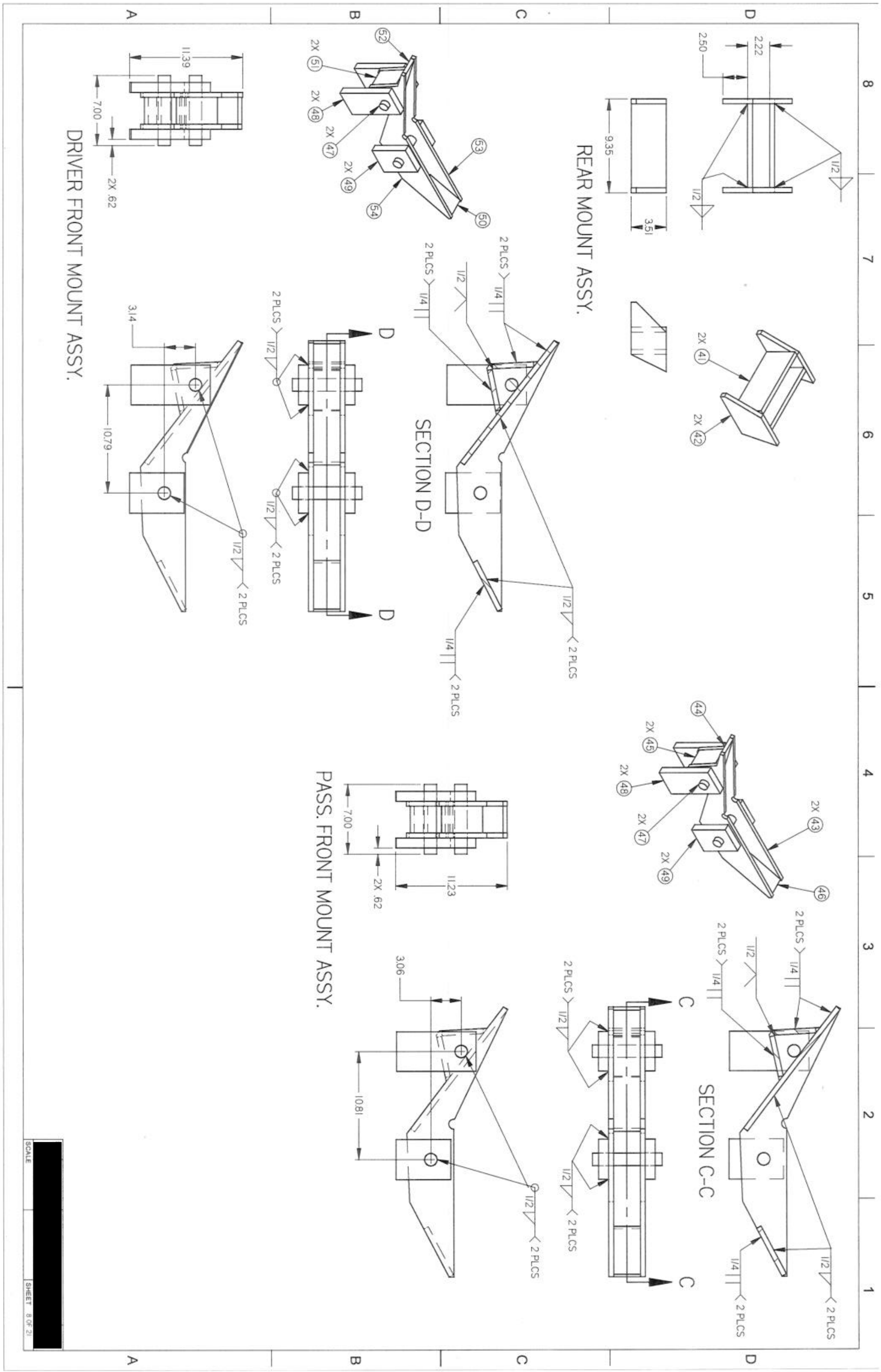
ASSEMBLY WELDMENT
SECTION A-A

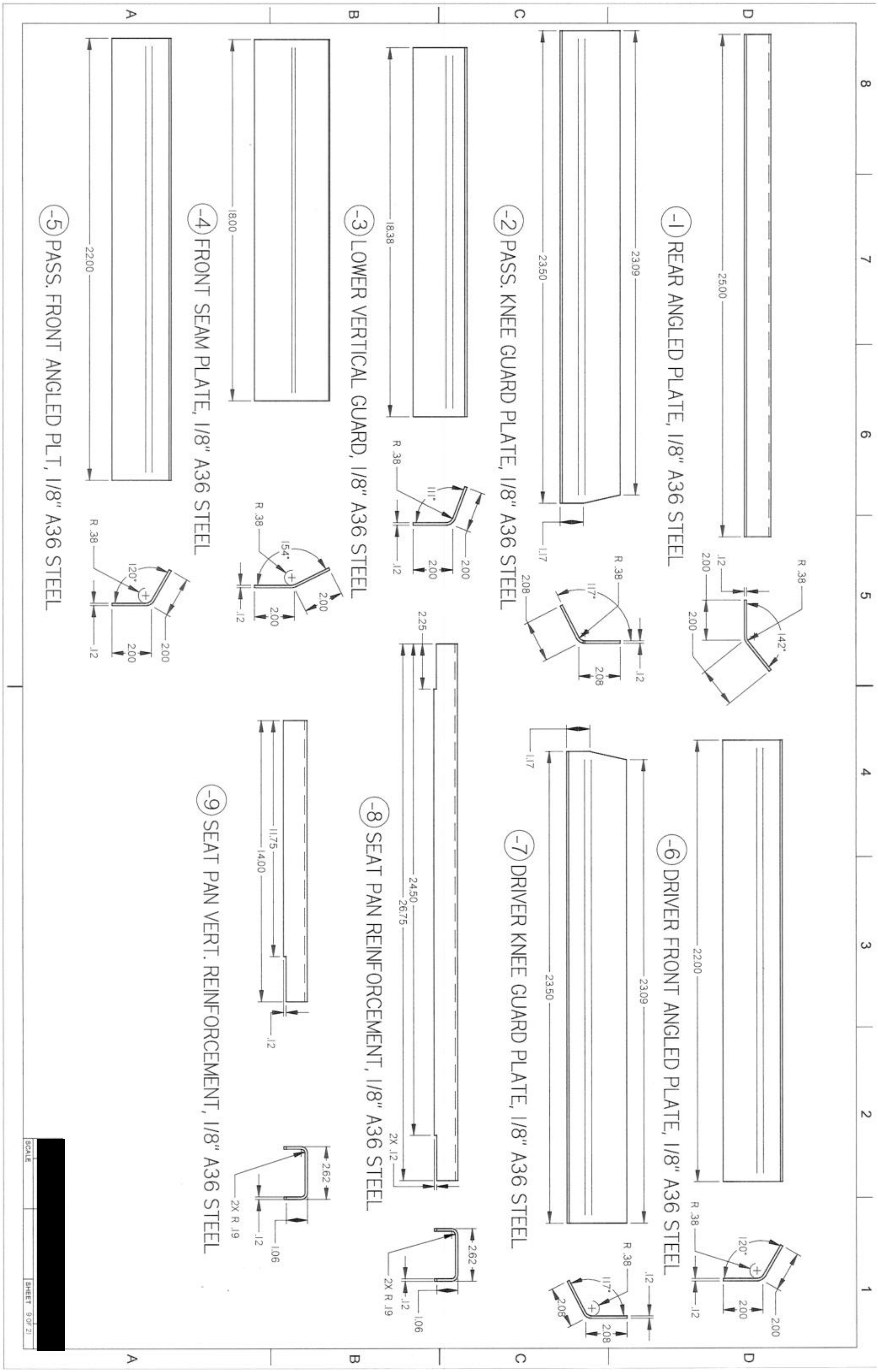

[redacted]
ASSEMBLY WELDMENT (CONT.)
SECTION B-B
SECTION C-C
SECTION D-D
(96.98)
(84.31)
(72.76)
(77.33)
(23.20)
(21.22)
(11.02)
2X (80°)
2X (76°)
(104°)
(102°)
(106°)
102°
2 PLCS
SCALE
SHEET 4 OF 21
[redacted]

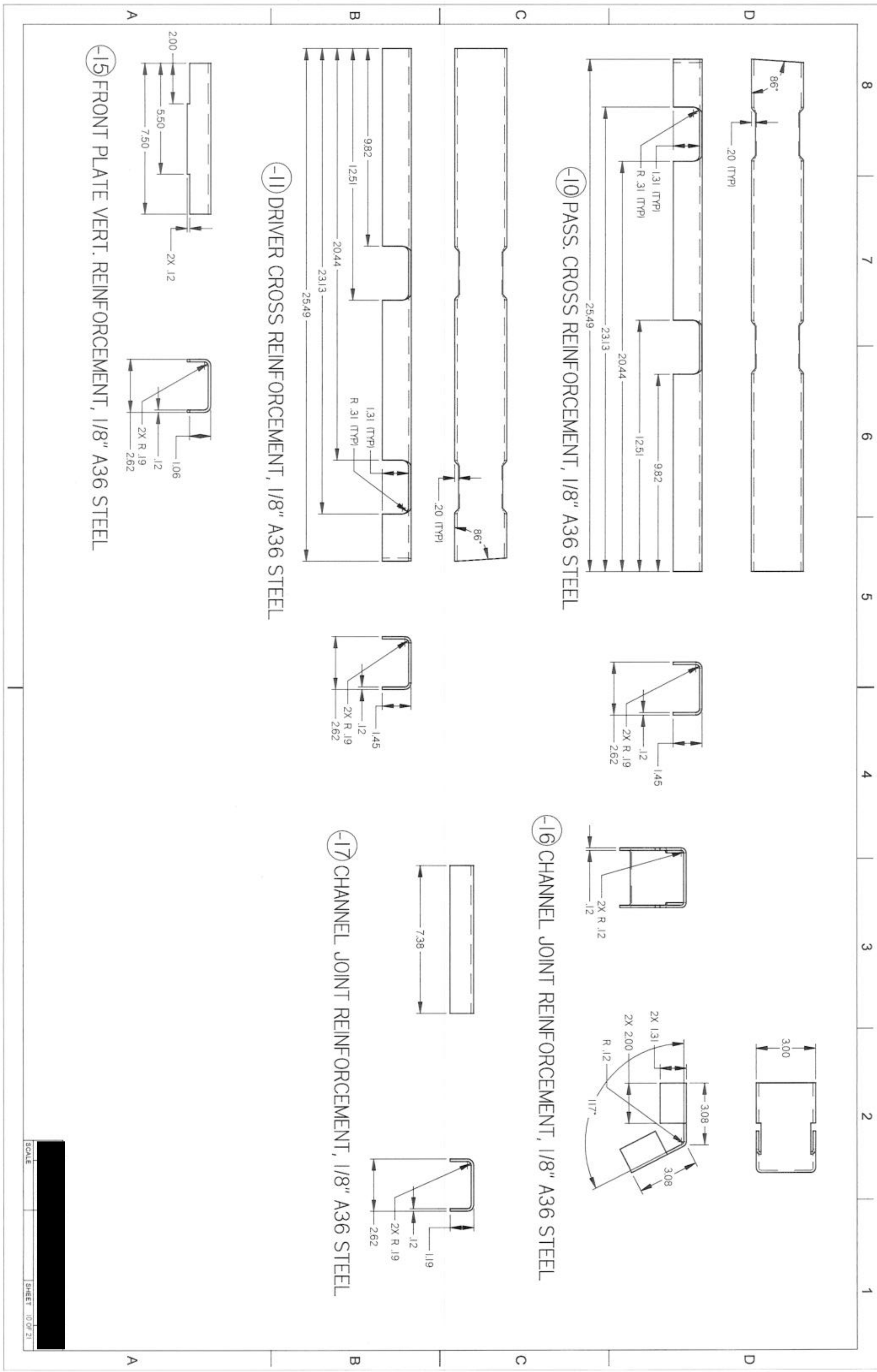

SEAM PLATE WELDMENT
SECTION E-E
SECTION F-F
2 PLCS GRIND FLUSH IN AREA OF THE I-BEAMS
SCALE
SHEET 5 OF 21

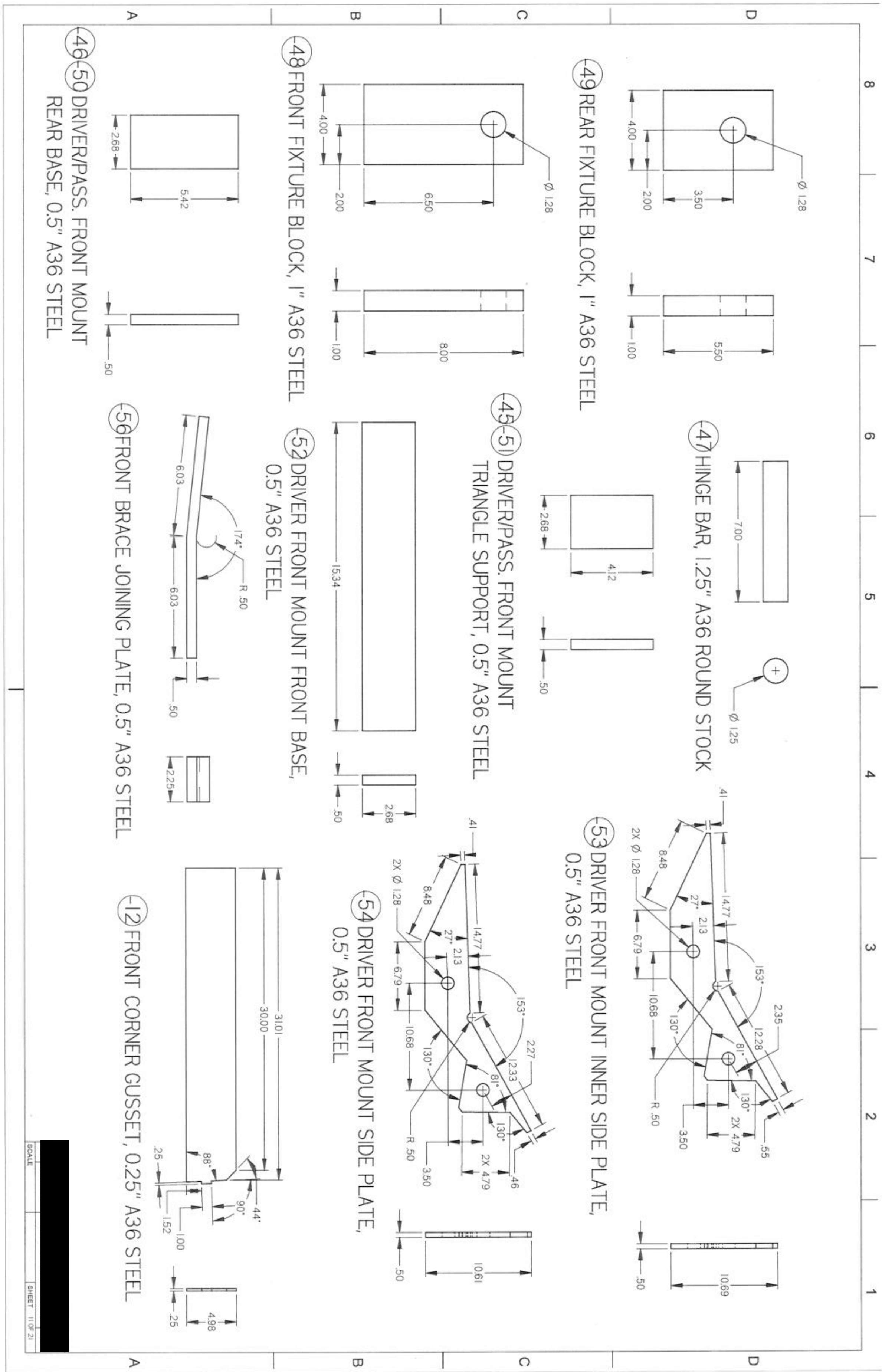

[redacted] FRAME REINFORCEMENT WELDMENT
[redacted] I-BEAM WELDMENT
4 PLCS
4X (10)
2X (5.37)
4 PLCS
2X (9.72)
2X (8.00)
4X (16)
4X (48)
1/8
4 PLCS
4X (4)
4X (11)
8 PLCS
54.0
41.0
28.0
1/4
6 PLCS
46.00
SCALE
SHEET 6 OF 21
A
B
C
D
8
7
6
5
4
3
2
1

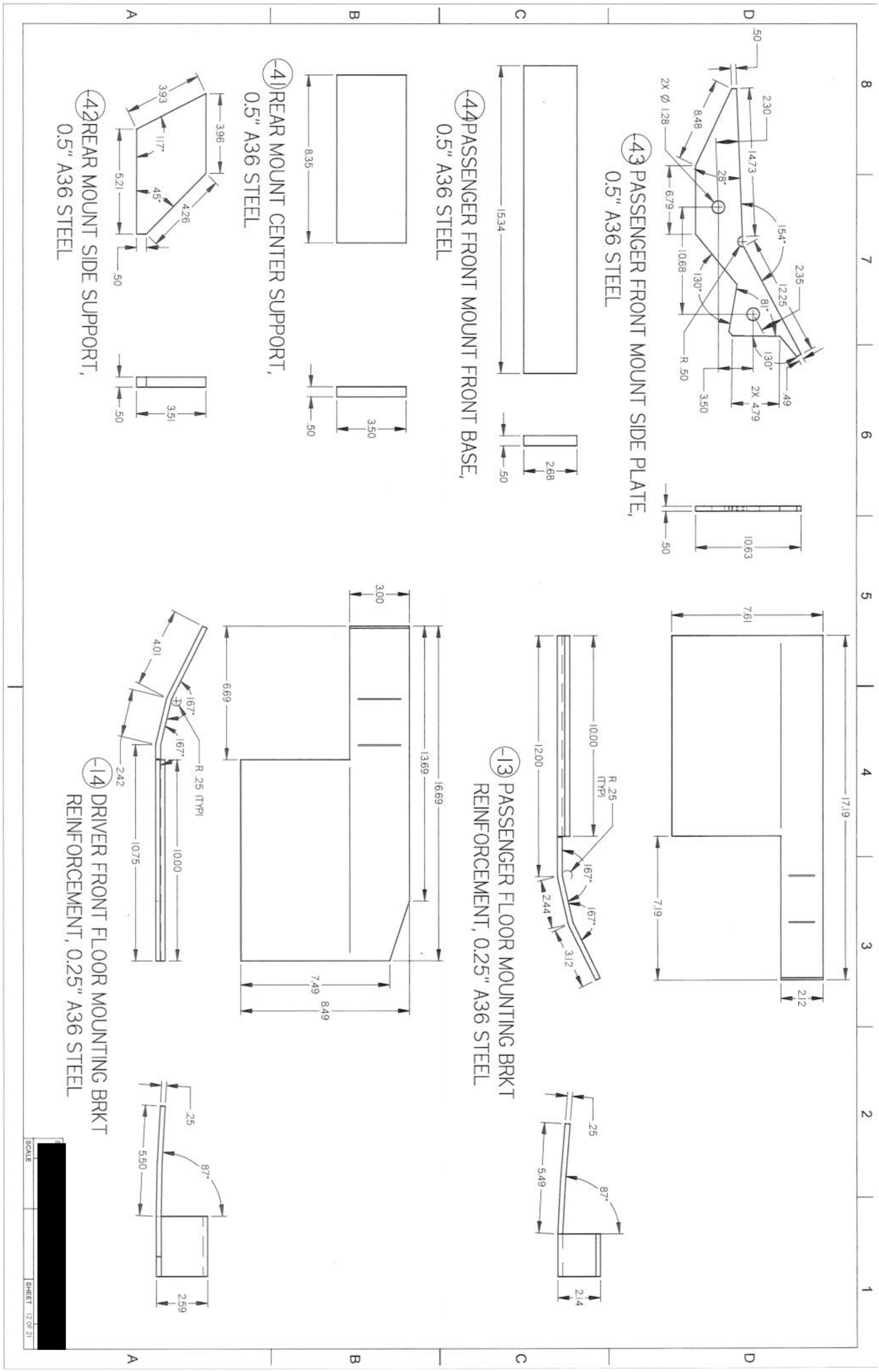

SEAT PAN PLATE AUX. VIEW
ASSEMBLY APPURTENANCE WELDMENT
VERTICAL FLOOR PLATE AUX. VIEW
REAR FLOOR PLATE AUX. VIEW
FRONT PLATE AUX. VIEW
16 PLCS
6 PLCS
8 PLCS
SCALE
SHEET 7 OF 21

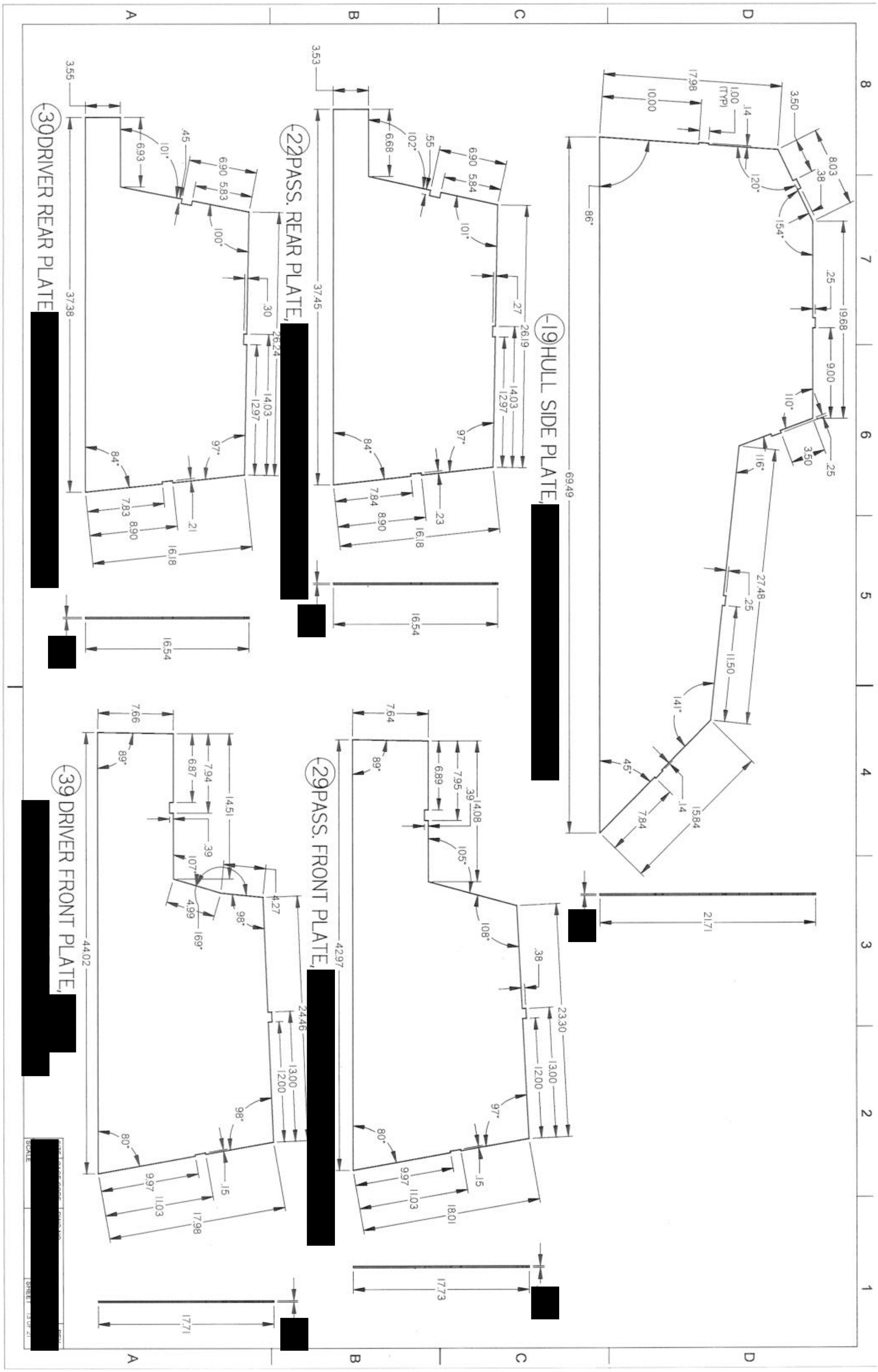

REAR MOUNT ASSY.
DRIVER FRONT MOUNT ASSY.
PASS. FRONT MOUNT ASSY.
SECTION D-D
SECTION C-C
SCALE
SHEET 8 OF 21

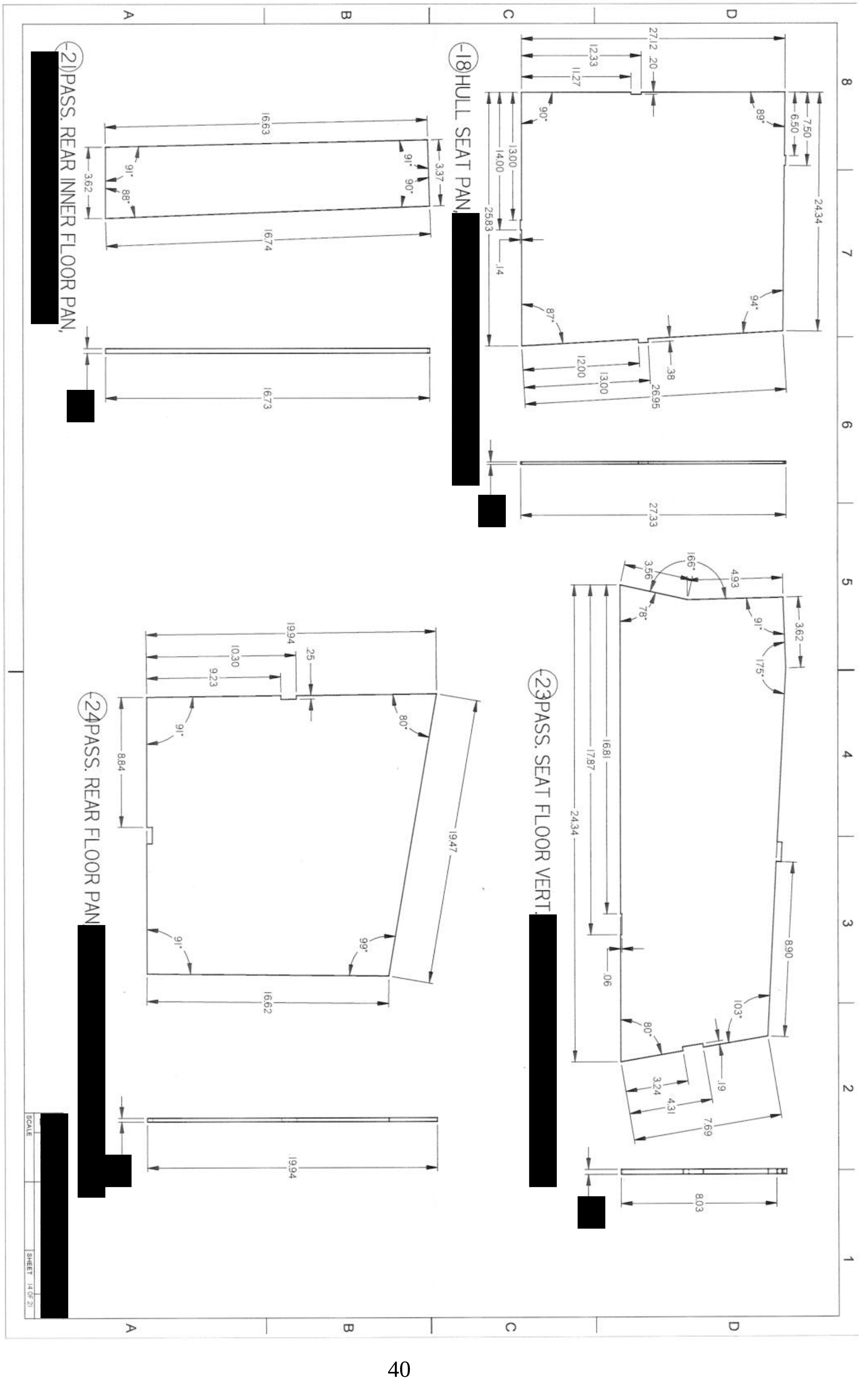

-1 REAR ANGLED PLATE, 1/8" A36 STEEL
-2 PASS. KNEE GUARD PLATE, 1/8" A36 STEEL
-3 LOWER VERTICAL GUARD, 1/8" A36 STEEL
-4 FRONT SEAM PLATE, 1/8" A36 STEEL
-5 PASS. FRONT ANGLED PLT, 1/8" A36 STEEL
-6 DRIVER FRONT ANGLED PLATE, 1/8" A36 STEEL
-7 DRIVER KNEE GUARD PLATE, 1/8" A36 STEEL
-8 SEAT PAN REINFORCEMENT, 1/8" A36 STEEL
-9 SEAT PAN VERT. REINFORCEMENT, 1/8" A36 STEEL
SCALE
[redacted]
SHEET 9 OF 21

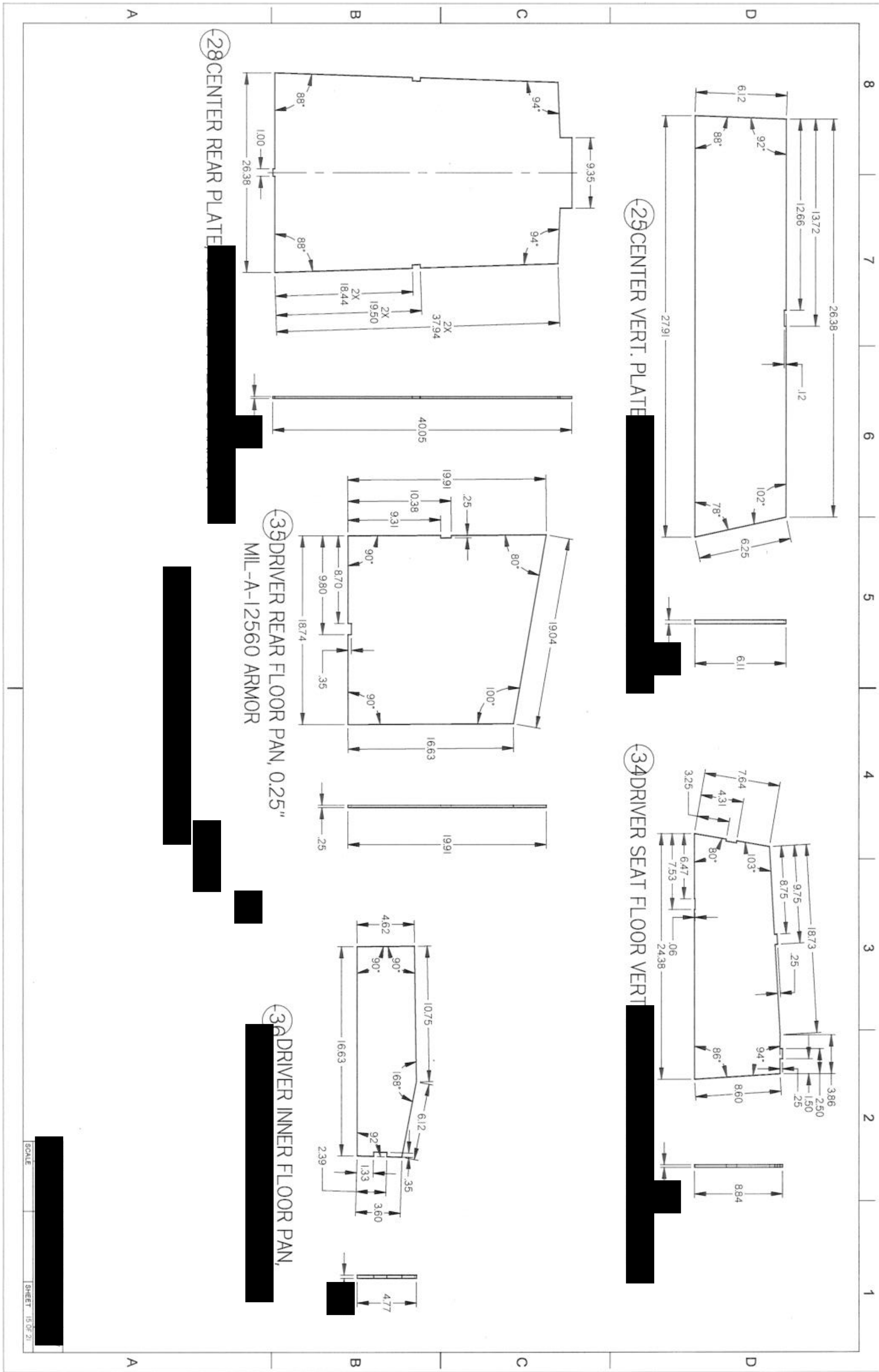

-10 PASS. CROSS REINFORCEMENT, 1/8" A36 STEEL
-11 DRIVER CROSS REINFORCEMENT, 1/8" A36 STEEL
-15 FRONT PLATE VERT. REINFORCEMENT, 1/8" A36 STEEL
-16 CHANNEL JOINT REINFORCEMENT, 1/8" A36 STEEL
-17 CHANNEL JOINT REINFORCEMENT, 1/8" A36 STEEL
25.49
23.13
20.44
12.51
9.82
1.31 (TYP)
R .31 (TYP)
.20 (TYP)
86°
1.45
.12
2X R .19
2.62
1.06
2.00
5.50
7.50
2X .12
2X R .12
7.38
3.00
3.08
2X 1.31
2X 2.00
R .12
117°
1.19
SCALE
[redacted]
SHEET 10 OF 21

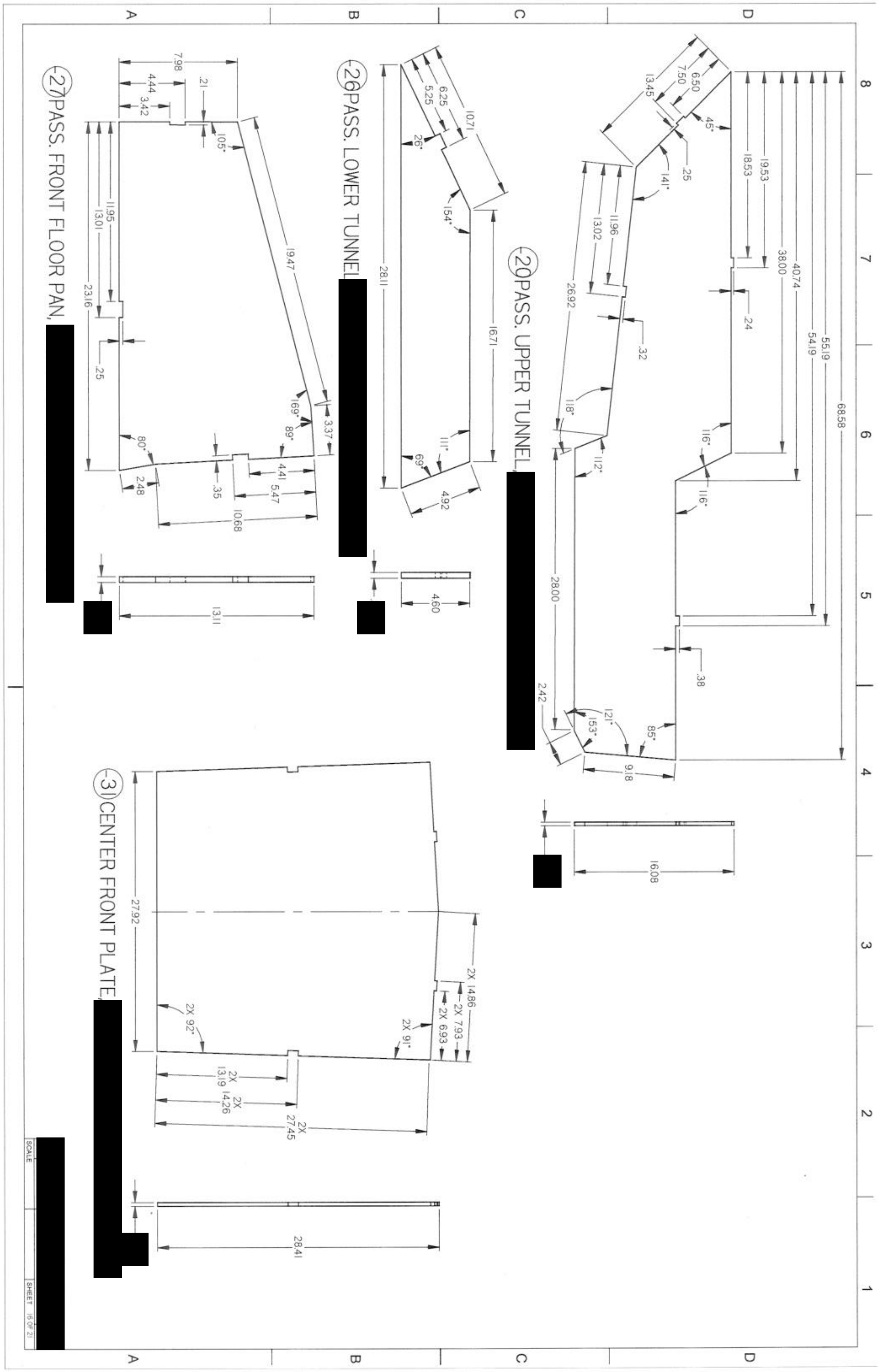

-49 REAR FIXTURE BLOCK, 1" A36 STEEL
-48 FRONT FIXTURE BLOCK, 1" A36 STEEL
-46 -50 DRIVER/PASS. FRONT MOUNT REAR BASE, 0.5" A36 STEEL
-47 HINGE BAR, 1.25" A36 ROUND STOCK
-45 -51 DRIVER/PASS. FRONT MOUNT TRIANGLE SUPPORT, 0.5" A36 STEEL
-52 DRIVER FRONT MOUNT FRONT BASE, 0.5" A36 STEEL
-56 FRONT BRACE JOINING PLATE, 0.5" A36 STEEL
-53 DRIVER FRONT MOUNT INNER SIDE PLATE, 0.5" A36 STEEL
-54 DRIVER FRONT MOUNT SIDE PLATE, 0.5" A36 STEEL
-12 FRONT CORNER GUSSET, 0.25" A36 STEEL
SCALE
SHEET 11 OF 21

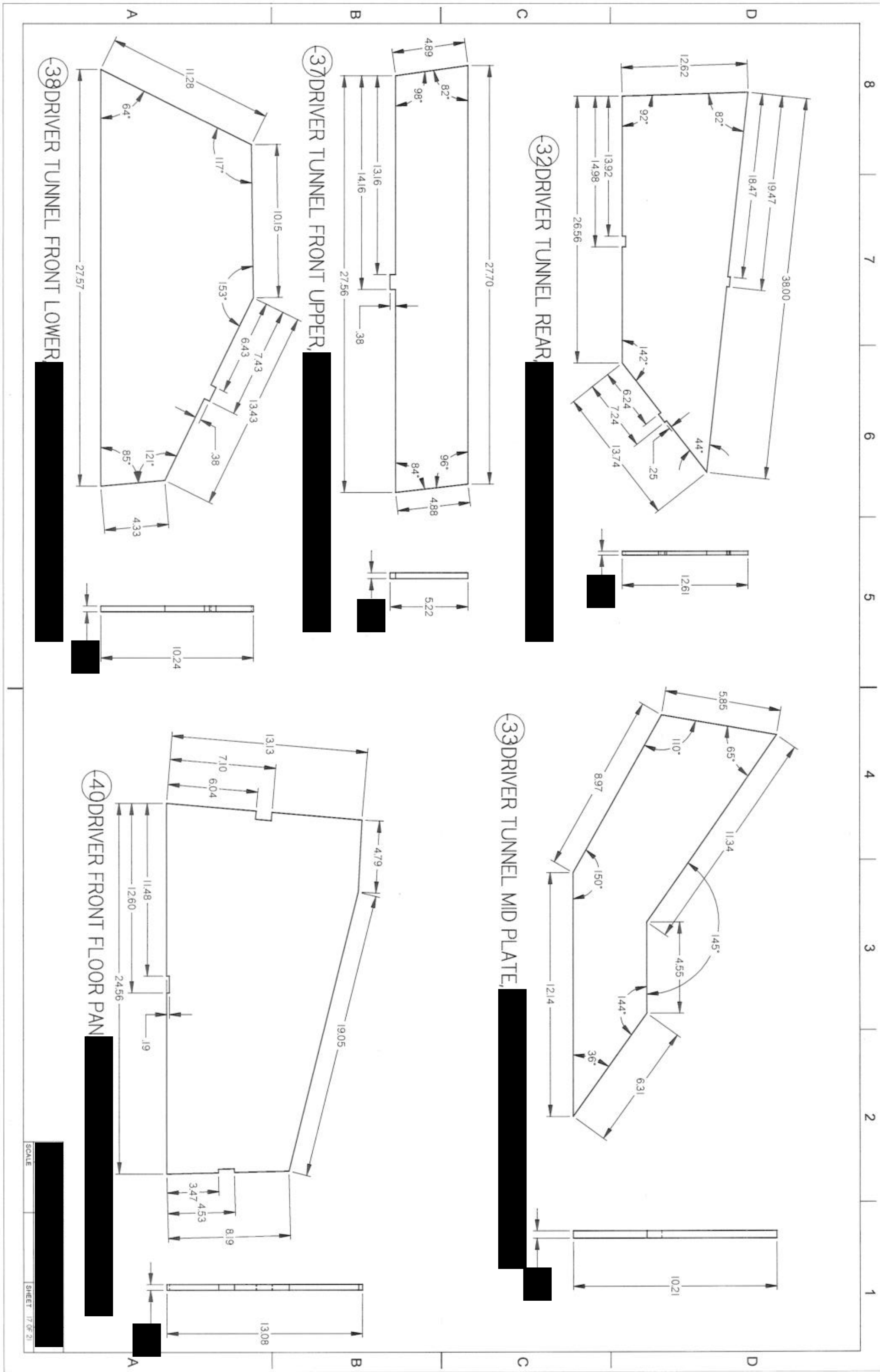

-43 PASSENGER FRONT MOUNT SIDE PLATE,
0.5" A36 STEEL
-44 PASSENGER FRONT MOUNT FRONT BASE,
0.5" A36 STEEL
-41 REAR MOUNT CENTER SUPPORT,
0.5" A36 STEEL
-42 REAR MOUNT SIDE SUPPORT,
0.5" A36 STEEL
-13 PASSENGER FLOOR MOUNTING BRKT
REINFORCEMENT, 0.25" A36 STEEL
-14 DRIVER FRONT FLOOR MOUNTING BRKT
REINFORCEMENT, 0.25" A36 STEEL
SCALE
SHEET 12 OF 21
[redacted]

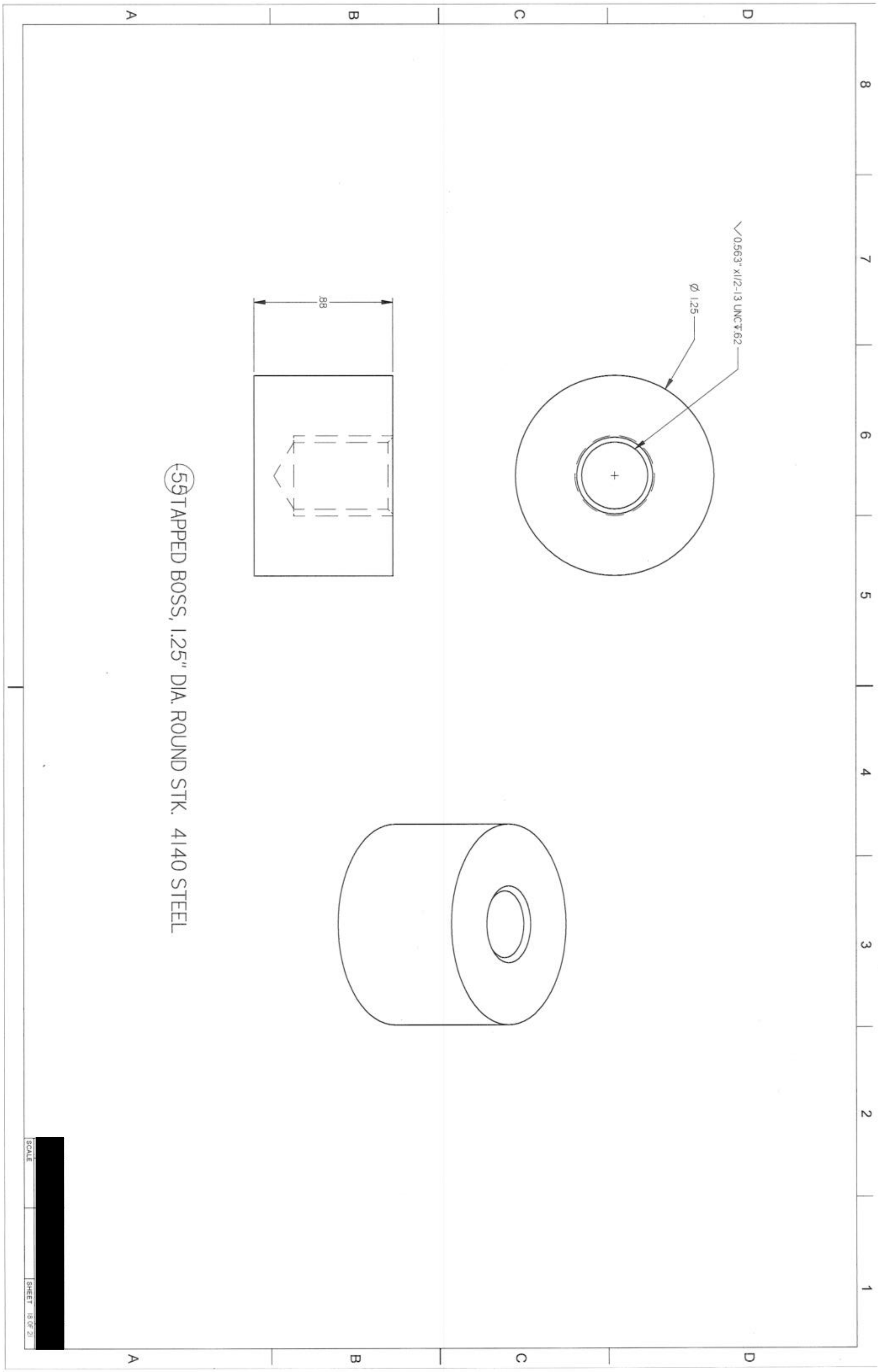

-30 DRIVER REAR PLATE, [redacted]
-22 PASS. REAR PLATE, [redacted]
-19 HULL SIDE PLATE, [redacted]
-39 DRIVER FRONT PLATE, [redacted]
-29 PASS. FRONT PLATE, [redacted]

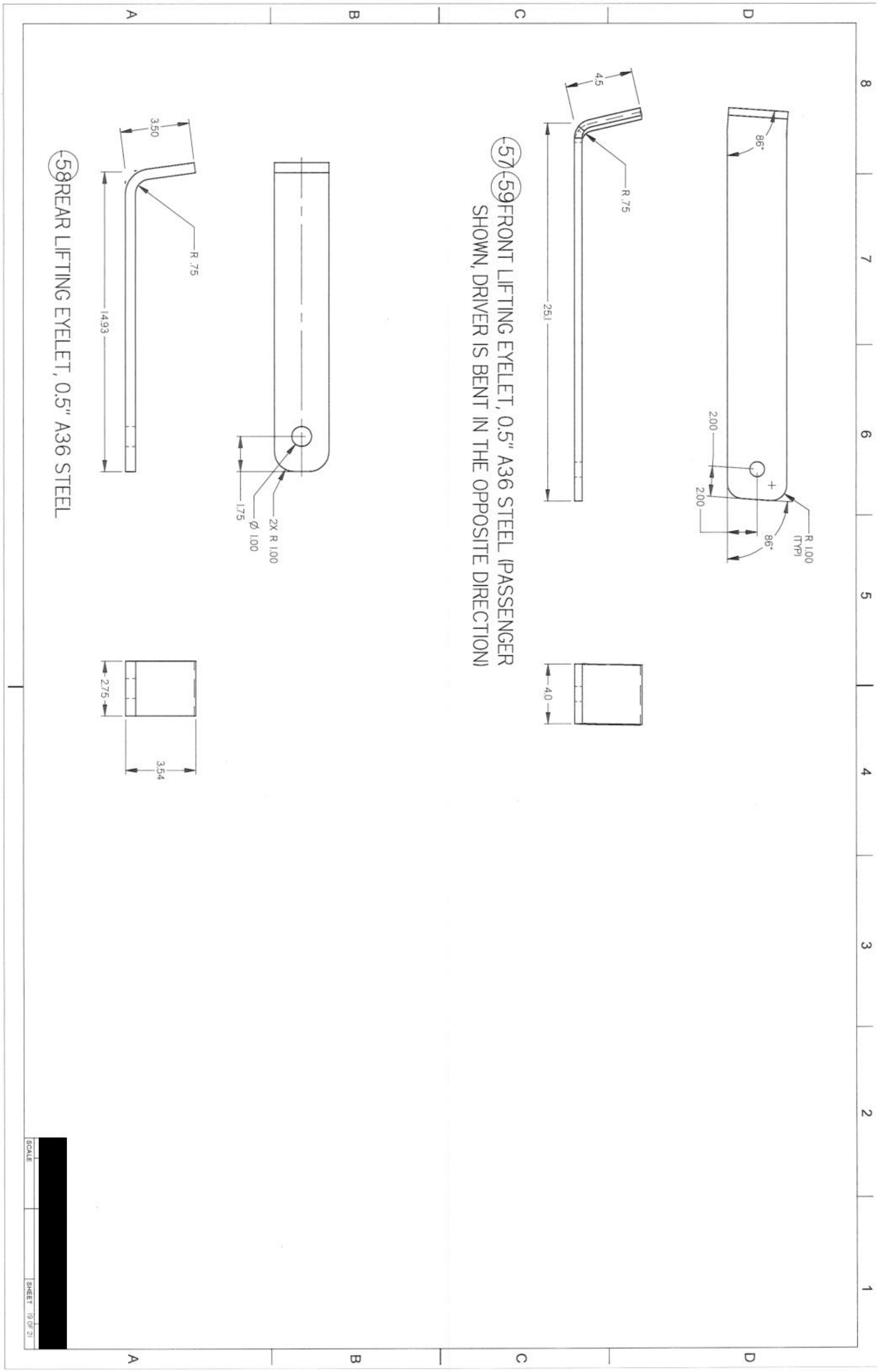

-21 PASS. REAR INNER FLOOR PAN, [redacted]
-18 HULL SEAT PAN, [redacted]
-23 PASS. SEAT FLOOR VERT. [redacted]
-24 PASS. REAR FLOOR PAN [redacted]
SCALE
SHEET 14 OF 21


-28 CENTER REAR PLATE [redacted]
-25 CENTER VERT. PLATE [redacted]
-35 DRIVER REAR FLOOR PAN, 0.25"
MIL-A-12560 ARMOR [redacted]
-34 DRIVER SEAT FLOOR VERT [redacted]
-36 DRIVER INNER FLOOR PAN, [redacted]
SCALE
SHEET

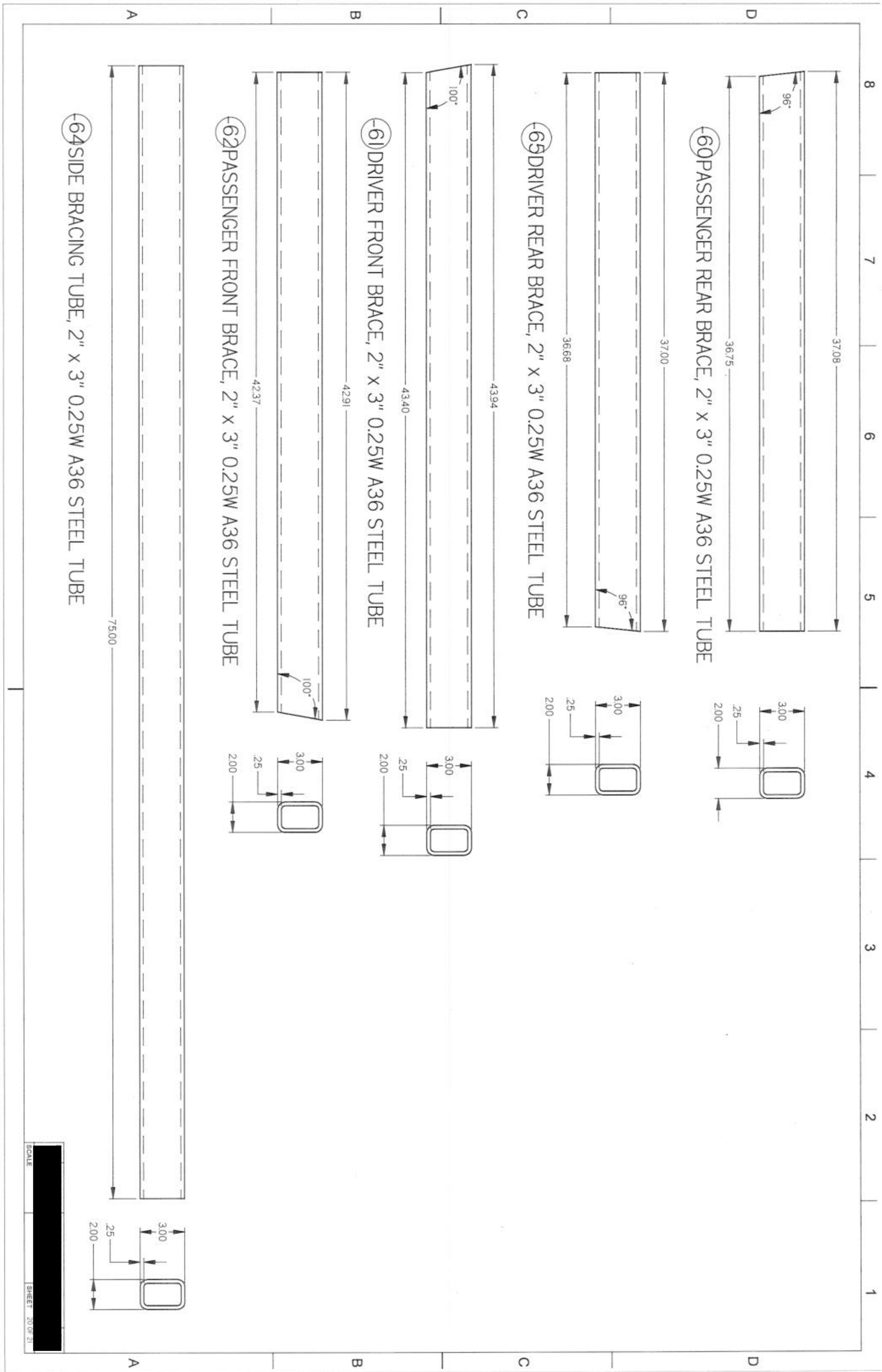

-27 PASS. FRONT FLOOR PAN, [redacted]
-26 PASS. LOWER TUNNEL [redacted]
-20 PASS. UPPER TUNNEL [redacted]
-31 CENTER FRONT PLATE, [redacted]
SCALE
SHEET 15 OF 21

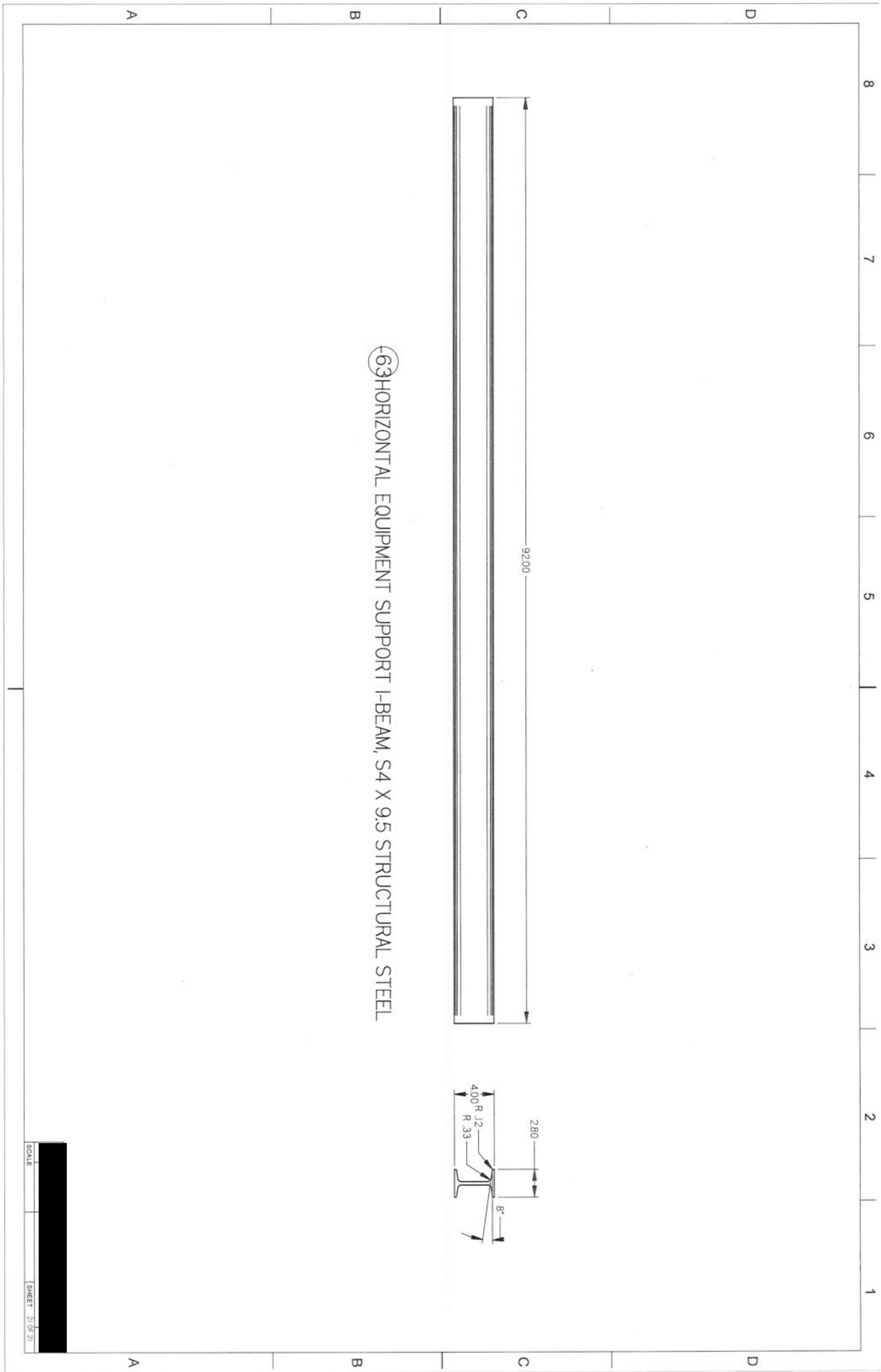

-38 DRIVER TUNNEL FRONT LOWER, [redacted]
-37 DRIVER TUNNEL FRONT UPPER, [redacted]
-32 DRIVER TUNNEL REAR, [redacted]
-33 DRIVER TUNNEL MID PLATE, [redacted]
-40 DRIVER FRONT FLOOR PAN [redacted]
SCALE [redacted]
SHEET 17 OF 21


0.563" x1/2-13 UNC ↧.62
Ø 1.25
.88
55 TAPPED BOSS, 1.25" DIA. ROUND STK. 4140 STEEL
SCALE
[redacted]
SHEET 18 OF 21

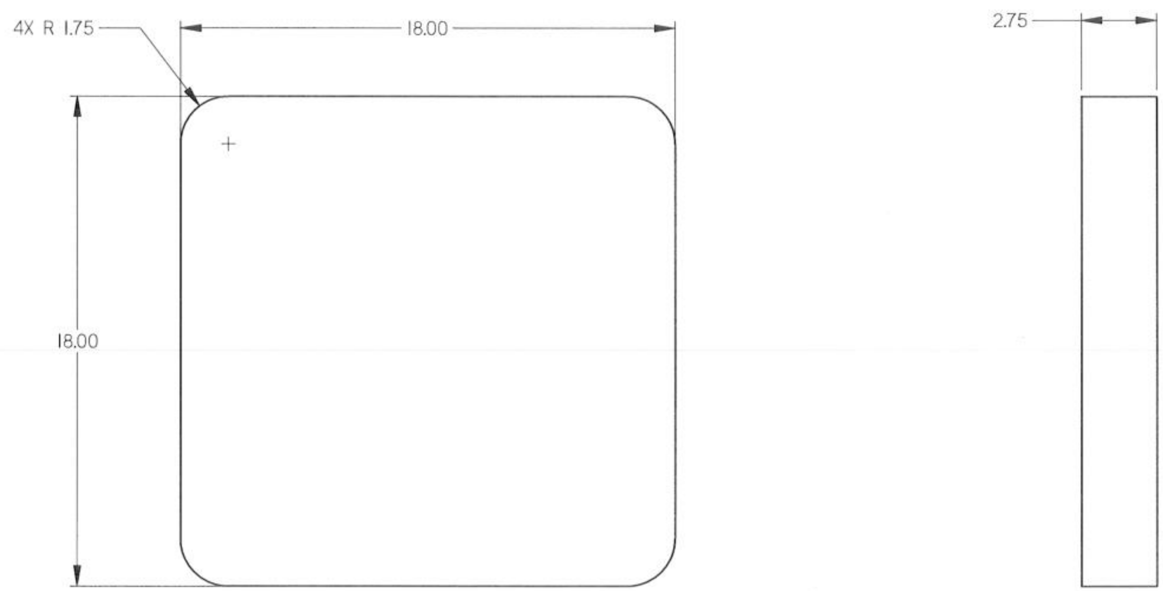


57 59 FRONT LIFTING EYELET, 0.5" A36 STEEL (PASSENGER SHOWN, DRIVER IS BENT IN THE OPPOSITE DIRECTION)
58 REAR LIFTING EYELET, 0.5" A36 STEEL
4.5
R .75
25.1
4.0
86°
2.00
2.00
R 1.00 (TYP)
3.50
14.93
2X R 1.00
Ø 1.00
1.75
2.75
3.54
SCALE
[redacted]
SHEET 19 OF 21


-60 PASSENGER REAR BRACE, 2" x 3" 0.25W A36 STEEL TUBE
-65 DRIVER REAR BRACE, 2" x 3" 0.25W A36 STEEL TUBE
-61 DRIVER FRONT BRACE, 2" x 3" 0.25W A36 STEEL TUBE
-62 PASSENGER FRONT BRACE, 2" x 3" 0.25W A36 STEEL TUBE
-64 SIDE BRACING TUBE, 2" x 3" 0.25W A36 STEEL TUBE
96°
37.08
36.75
37.00
36.68
100°
43.94
43.40
42.91
42.37
75.00
3.00
.25
2.00
SCALE
[redacted]
SHEET 20 OF 21


63
HORIZONTAL EQUIPMENT SUPPORT I-BEAM, S4 X 9.5 STRUCTURAL STEEL
92.00
4.00
R .12
R .33
2.80
8°
SCALE
SHEET 21 OF 21
[redacted]

1. REMOVE BURRS AND BREAK SHARP EDGES
2. FINISH PER 5.1.1 AND 20.24 OF MIL-STD-171, COLOR NO. 33446



PCN: Q01W3N
QTY: 3 EACH
FILENAME: 250LB_SIMULATED_WEIGHT
[redacted]

FIND NO.	QTY REQD	PART NO. OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	NOTE

PARTS LIST

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES
TOLERANCES ON:
FRACTIONS DECIMALS ANGLES
.XX ±.04 ±1°
.XXX ±.010

MATERIAL:
2.75" THICK MILD STEEL OR ANY 4XXX SERIES STEEL PLATE

DRAWN: J. FRIDAY
CHECKED
REVIEWED
APPROVED
DATE: 02 October 2008

LETTERKENNY ARMY DEPOT
CHAMBERSBURG, PA. 17201

250 LB. SIMULATED WEIGHT

SIZE	CAGE CODE	DWG NO.	REV
D	0NDM7	MXXXX	

SCALE
SHEET 1 OF 1

REVISION / SHEET
SHEET REVISION RECORD
NEXT ASSY | USED ON
APPLICATION

REVISIONS
LTR | DESCRIPTION | DATE | APPROVED

APPENDIX B

TEST RESULTS

Not included: Available upon request with valid security clearance

APPENDIX C

ACCELEROMETER DATA ANALYSIS

Not included: Available upon request with valid security clearance

APPENDIX D

ABET PROGRAM OUTCOMES

ABET PROGRAM OUTCOMES

Upon graduation, students receiving the Bachelor of Science in Mechanical Engineering Degree from Kettering University will have the following knowledge, skills, and abilities:

A. An ability to apply knowledge of mathematics, science and engineering.

   This investigation required the ability to apply the knowledge of mathematics, science, and engineering to design, test, and evaluate the effectiveness of underbody armor applications on a MTV.

B. An ability to design and conduct experiments, as well as to analyze and interpret data.

   This effort revolved around the design and conduct of experiments, generating a wealth of data that was subsequently analyzed to arrive at the project's conclusion.

C. An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.

   This ability was reflected thoroughly in the test asset development stages of the project, in which a multitude of test hulls, armor kits, and fixtures were required to accomplish the task at hand. For example, in accordance with economic factors, R2 was eliminated immediately because of its excessive price. Also, hull testing was pursued over full vehicle testing and a spent vehicle chassis was implemented as a fixture all in an effort to minimize cost.

D. An ability to function on multi-disciplinary teams.

   This project would have not been feasible without working jointly with numerous satellite teams to leverage their expertise and capabilities. As specified throughout the thesis, the author was required to work with ARL, CASSI, GVPM, LEAD, and ATC; to ensure a comprehensive solution was achieved.

E. An ability to identify, formulate, and solve engineering problems.

The ability to identify, formulate, and solve engineering problems was required almost continually throughout this project. As evidenced in the thesis, a multitude of technical solutions were required to integrate a substantial amount of armor onto a vehicle not originally intended for it.

F. An understanding of professional and ethical responsibility.
This project demanded frequent interaction with sensitive information. Professional and ethical responsibility was critical to ensuring all information was controlled properly. Also, it was important that all findings were reported accurately to ensure the safety of United States military personnel.

G. An ability to communicate effectively.

The immense interaction with subsidiary groups required effective and efficient communication skills to ensure all elements were working in unison with a clear understanding of functions required.

H. The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.

The result of this thesis will influence the path forward regarding the application of AoA to Tactical Wheel Vehicles. Said armor has the potential to prevent hundreds if not thousands of U.S. causalities, vastly altering the course of any military conflict. Also, this project was conducted via tax payer dollars, it is demanded that this funding be spent wisely to maximize our national security.

I. A recognition of the need for, and an ability to engage in lifelong learning.

United States adversaries are constantly evolving their weapons to exploit proposed United States vulnerabilities. Consequently, continuous expansion of one's education is vital to maintain cutting edge capabilities for defeating said threats.

J. A knowledge of contemporary issues.

This is a volatile era in the United State's history. Our military is currently engaged in conflicts spanning two fronts. We are persecuted for our nation's belief in freedom and the rights it grants to all its citizens, regardless of race, sex, or religion. Additional threats to the United State's national security continually emerge with little indication of future impediment. Accordingly, it is of the upmost importance that all United States military personnel required to go into harm's way are equipped with the most capable technology to ensure their success and survivability.

K. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

This project required the use computer based analytical software to analyze test data and computer aided engineering software was used routinely for test asset design.

L. Familiarity with statistics and linear algebra.

A basic understanding of statics and linear algebra was necessary to comprehend armor recipe assessments which incorporated a given threat's probability of producing fragmentation consisting of range of weights and speeds.

M. A knowledge of chemistry and calculus-based physics with a depth in at least one of them.

A knowledge of physics was required to understand the threat mechanisms associated with IEDs and their respective defeat mechanisms. Overall, it was important to understand how materials and systems reacted to large forces, especially when analyzing subsequent test data.

N. An ability to model and analyze inter-disciplinary mechanical/electrical/hydraulic systems.

To ensure AoA kits would not jeopardize vehicle performance characteristics, multiple analyses were conducted that incorporated mechanical and hydraulic systems.

O. An ability to work professionally in the area of thermal systems including the design and realization of such systems.

A basic understanding of thermal systems in relation to the detonation of explosive devices was required to appreciate the threat mechanisms and resulting defeat mechanisms at hand.

P. An ability to work professionally in the area of mechanical systems including the design and realization of such systems.

An understanding of mechanical systems was required to ensure the implemented fixtures would exhibit sufficient shear strength to withstand the forces experienced during an IED event. Also, it was required to ensure axial loading of the underbody armor kit attachment bolts would not fail from blast pressures.